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Syntax and parametric analysis of superblock patterns

John Peponis^{*1}, Chen Feng^{*1}, David Green², Dawn Haynie³, Sung Hong Kim⁴, Qiang Sheng⁵, Alice Vialard^{1,6} and Haofeng Wang⁷

* Corresponding authors, who have equally contributed to this paper.

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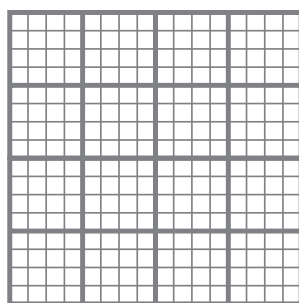
⁴ University of Seoul

⁵ Tianjin University

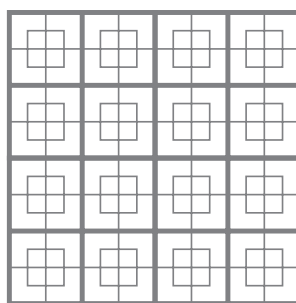
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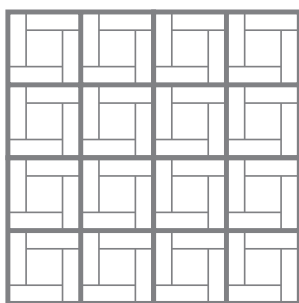
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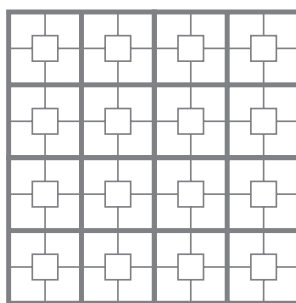
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Syntax and parametric analysis of superblock patterns

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A particular kind of street network is examined, where strong differentiation between scales of syntactic structure is evident: supergrids of primary roads, with inserted local streets. Computational formulae are provided to describe simple regular systems and clarify the nature of the syntactic differentiation of scales. The focus is on the linear extension of streets and also on distances measured according to direction changes. A small sample of examples from Chicago, Los Angeles, Beijing and Seoul as well as the Doxiadis plan for sector G7 of Islamabad and the Perry-Whitten neighborhood plan for New York are also analyzed, leading to estimates of a number of remarkably consistent parameters that can function as benchmarks for design exploration or theoretical experimentation. An experiment whereby the fabric of the historic centers of small French towns is inserted into a supergrid at 0.5 mile intervals is also described to explore the scale and character of inserted systems in comparison to historic urban fabrics. The work leads to a methodological proposition. Supergrids can best be conceptualized by decomposing the analysis of closeness centrality (integration) into two components: the mean directional distances associated with the supergrid as an independent system, and the mean directional distances from inserted streets to the nearest supergrid element (step depth in DepthMap). Decomposition responds to a theoretical idea: cognitive maps comprise a skeleton system relative to which other parts can be 'placed' and related. Decomposition also responds to a practical purpose: in order to design one must work with intuitively accessible parameters that can be controlled within the site and scope of the design.

Keywords:

Scale, supergrids, decomposition, design benchmarks, superblocks.

1. Introduction: Scale as a property of the internal differentiation of urban areas

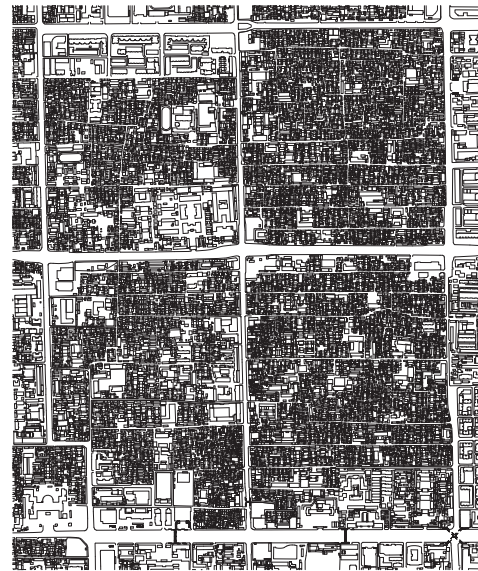
The question of urban scale can be approached in terms of size, internal differentiation or the way in which size and internal differentiation interact. Shpuza (2014), for example, looks at the variation of the means of syntactic measures as cities grow larger in area and in the number of axial lines used to represent their street network. Hillier (2002), on the other hand, distinguishes between the few long primary streets which form a primary connecting system of historic towns and the many shorter streets which form the bulk of their fabric. In this paper we look at scaling as an aspect of the internal differentiation of street networks which interacts

with size. More particularly we are interested in a particular expression of scale whereby a relatively dense network of local streets is inserted within the areas defined by a higher order network of major streets or thoroughfares. One way to think of such systems is as 'superblocks' defined by the major streets, further divided into urban blocks by the minor streets.

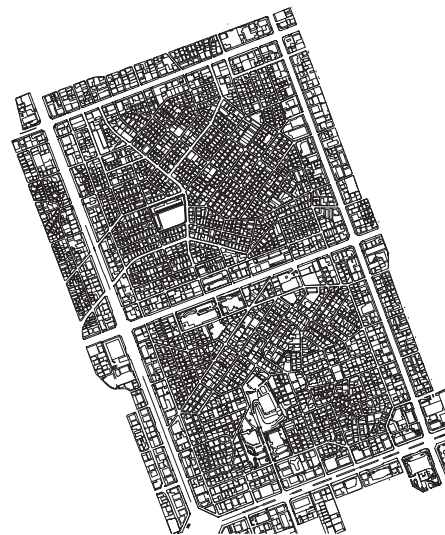
Figures 1 and 2 show four urban areas in Beijing (inside the 2nd ring road), Seoul (Gangnam, south of the Han river), Chicago (Belmont Cragin) and Los Angeles (Westminster), all of which display such a structure of superimposed scales of organisation.

In the case of Chicago, rights of way are all about 20 meters but the number of available lanes is different on primary and secondary streets. Figure 3 shows two design proposals inspired by the same idea: The first is Doxiadis' plan for Islamabad sector G7, 1968, intended for a community of 50,000 people. This is presented in a drawing in the Doxiadis archive and is similar to the drawings in Ekistics (Doxiadis, 1968) but quite different from the present situation on the ground. The plan adjusts the Hippodamian system to create stable local communities, each with its own neighborhoods, inserted within an expanding supergrid of freeways spaced at about 1 mile intervals. It departs from the principles of modernism exemplified in Brasilia or Chandigarh and represents a seminal late modern effort to come up with research-based principles for laying out streets as a framework for the dynamic evolution of the city. The second is Perry and Whitten's proposal for urban neighborhoods for about 5,000-6,000 people (Perry et al., 1929), one of the most influential proposals in US planning. The typical regular street grid of New York is interrupted and deformed, to define an identifiable neighborhood. Within the neighborhood, local stores, schools and playgrounds can be reached without crossing a major highway. The sinuosity of streets discourages through traffic.

The quantitative profile of the urban areas is shown in Table 1 below. It will be seen that super-block area is fairly consistent (between 64 and 70 hectares) as is the spacing of major street arteries (between 804 and 866 meters). The density of internal subdivision, however, varies. Street length per hectare ranges between 140 to 320 meters, and internal block area ranges between 0.5 and 3 hectares – note that block area is measured to the street center line and thus is overestimated in proportion to the width of the streets surrounding the blocks. Thus, we are predisposed to think of different morphologies within a relatively consistent



Coordinates of intersection at center:
39°55'55.82"N - 116°24'38.93"E



Coordinates of mid point of main avenue between superblocks:
37°30'21.19"N - 127°1'44.08"E

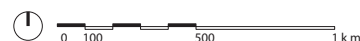


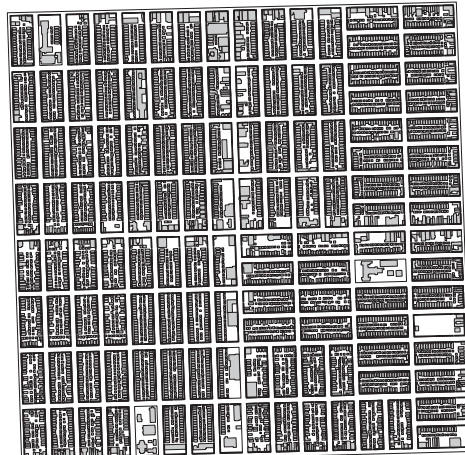
Figure 1:

Study areas in Beijing
(above) and Seoul
(below).

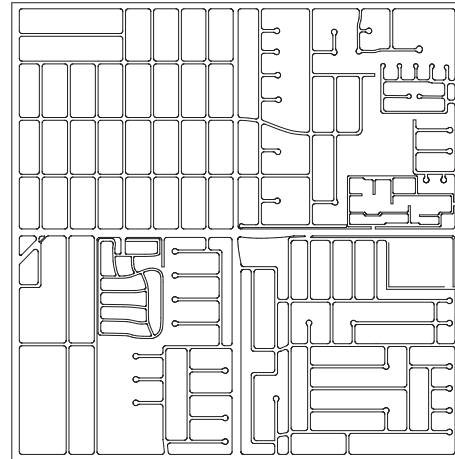
Peponis, J., Feng, C., Green, D., Haynie, D., Kim, S. H.,
Sheng, Q., Vialard, A. & Wang, H.

Figure 2:

Study areas in Chicago
(left) and Los Angeles
(right).



Coordinates of intersection at the center:
41°55'52.60"N - 87°45'58.49"W

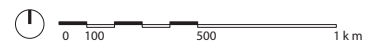
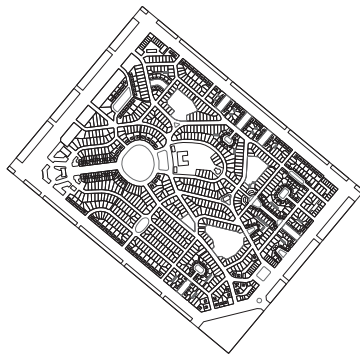


Coordinates of intersection at the center:
33°44'41.07"N - 117°58'51.48"W



Figure 3:

Perry and Whitten, pro-
posed plan for an urban
neighborhood in New
York, 1929, (left); and,
Doxiadis, proposed plan
for Sector G7, Islamabad,
1968, (right).



framework of major streets. From a syntactic point of view, differences can be readily identified on two dimensions of comparison. First, how far the superblocks are divided into distinct enclaves (as for example in Los Angeles) or elaborated into continuous urban fabrics (as in the other examples). Also, how far the internal street network appears like a distinct sub-system (as for example in Gangnam or the Perry Whitten neighborhood); or extends across superblocks to create a network of minor streets co-extensive with the network of major streets (as is evident in Chicago and to a lesser extent in Beijing). We will come to discuss the differences more systematically. First, however, we will look at some simple hypothetical grids in order to introduce theoretical ideas that we will subsequently bring to bear on the analysis of the actual urban forms.

2. Street length and directional distance in regular grids

In order to set a benchmark for subsequent comparisons, we first consider a regular grid with x intervals in the x -direction and y intervals in the y -direction, where the length of each x -interval is m and the length of each y -interval is n , as shown in Figure 4. Any individual grid of this type is fully specified by parameters x , y , m and n .

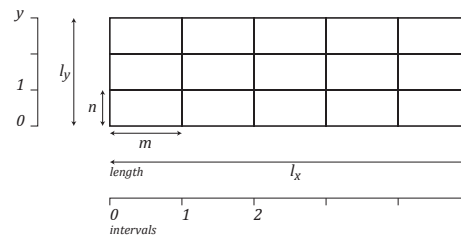


Figure 4:

Regular street grid and specification parameters.

	Beijing	Chicago	Gangnam Seoul	Islamabad G7	Los Angeles	Perry Whitten
Study area (ha)	347.76	263.03	138.66	295.19	258.76	64.84
Arterial spacing x-axis (m)	735.00	810.00	888.00	886.00	795.00	698.00
Arterial spacing y-axis (m)	922.00	811.00	787.00	845.00	813.00	938.00
Mean arterial spacing (m)	828.50	810.50	837.50	865.50	804.00	818.00
Arterial width (m)	15-45	20	20-35	21-24	25-40	37-50
Mean area of superblock (ha)	65.90	65.76	69.50	68.14	64.69	64.84
Superblock proportion ratio (longest side/shortest side)	1.25	1.00	1.13	1.05	1.02	1.34
Street length (km)	48.63	42.19	44.26	84.28	43.30	16.91
Street length/hectare (km)	0.14	0.16	0.32	0.29	0.17	0.26
Number of Road Segments	507	285	803	1468	323	267
Mean distance between intersections (m)	95.91	148.06	55.12	57.41	134.06	63.34
Internal street width (m)	3-7	20	3.5-12	6-16	12-20	4.5-30 (10-15 most frequent)
Number of blocks	141.00	128.00	272.00	556.00	86.00	85.00
Mean block area (ha)	2.47	2.05	0.51	0.53	3.01	0.76

Table 1:

Numeric profile of study areas.

The following measures describing the grid are defined:

L is the total street length in the system.

l_x is the length of a street in the x-direction.

l_y is the length of a street in the y-direction.

L_x is the total length of streets in the x-direction.

L_y is the total length of streets in the y-direction.

D_x is the mean directional distance from a random position on a street in the x-direction.

D_y is the mean directional distance from a random position on a street in the y-direction.

D is the mean of means of directional distance for the system as a whole, taking into account the proportional distribution of streets in the x and y directions.

Directional distance is measured according to the number of direction changes where the threshold angle for counting a direction change is specified parametrically (Peponis, Bafna and Zhang, 2008). Means are computed according to available street length rather than according to the number of street segments or line segments. In other words, the general form of equation for the mean directional distance, D_i , from a particular position is:

$$D_i = \frac{\sum_0^n a l_a}{L} \quad (1)$$

where a is directional distance; $0 \leq a \leq n$, where n is the minimum number of turns needed to reach the least easily accessible point in the network; l_a is the street length at the given value of directional distance, and L is the total street length in the network. The measure and calculation are explained in Figure 5.

Of course, in a regular grid, such as the one presented in Figure 4, there will be many positions that have the same mean directional distance (all those along a straight street, with multiple or very many street segments on it); even in a network

where every line is syntactically unique, all points along each line will have the same mean directional distance. Thus, we can refer to a *syntactic condition*, comprising all points that have the same mean directional distance from the network.

For a street network as a whole, the general form for the mean of means of directional distance is given by the form:

$$D = \frac{\sum D_i l_i}{L} \quad (2)$$

where D_i is the mean directional distance from a syntactic condition i , and l_i is the total street length that is characterized by this condition. The equations provided in this paper are specific instances of the general forms of equations 1 and 2, taking into account the parameters that define particular grids.

The following equations describe the measures defined above for regular grids of the kind presented in Figure 4, as a function of the parameters.

$$L = x(y + 1)m + y(x + 1)n \quad (3)$$

$$l_x = xm \quad (4)$$

$$l_y = yn \quad (5)$$

$$L_x = x(y + 1)m \quad (6)$$

$$L_y = y(x + 1)n \quad (7)$$

$$D_x = \frac{(x+1)yn+2xym}{L} \quad (8)$$

$$D_y = \frac{(y+1)xm+2xyn}{L} \quad (9)$$

$$D = \frac{D_x L_x + D_y L_y}{L} \quad (10)$$

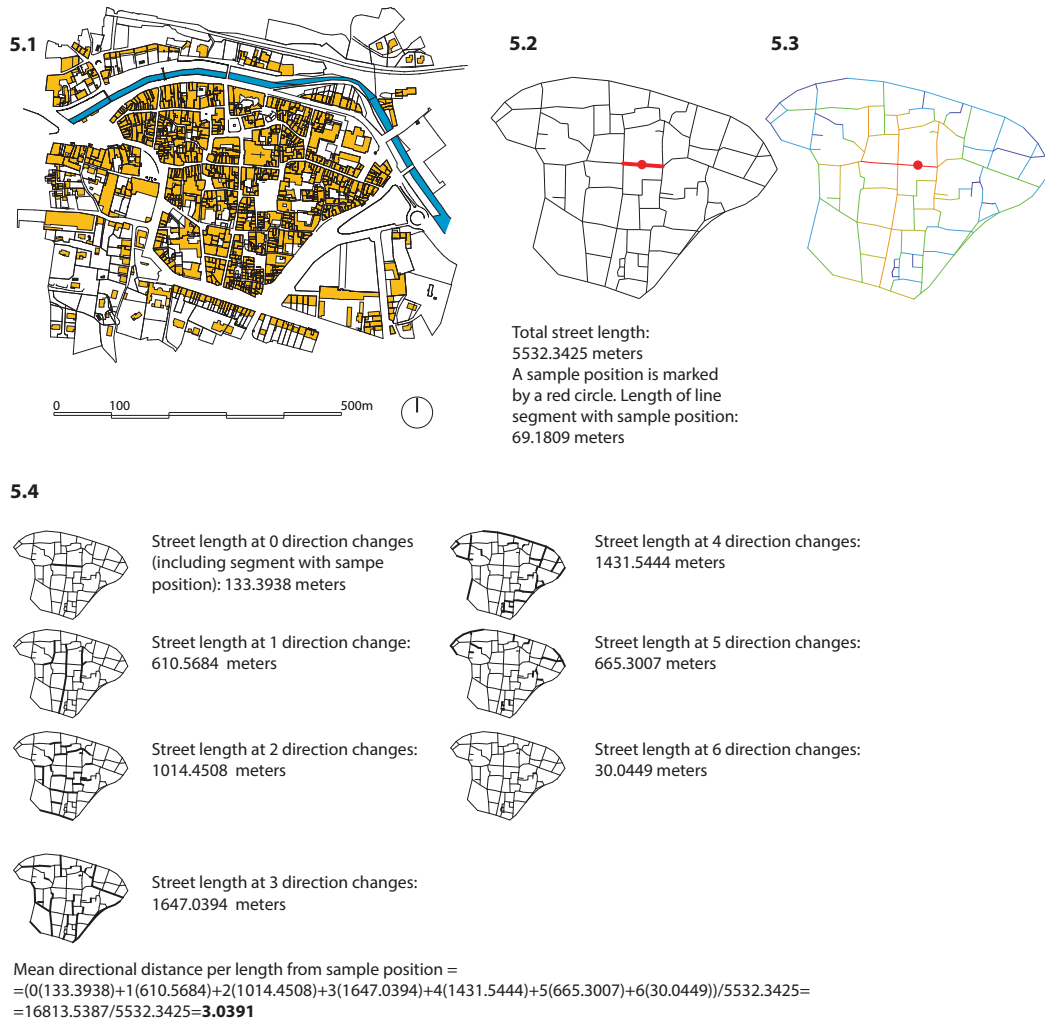


Figure 5:

Directional distance calculation, an example.

5.1: Cadastral map, city of Apt.

5.2: The street center line map with a sample position (red circle) mapped on it.

5.3: Line map colored according to increasing directional distances from a sample position, with 15° angle threshold for counting a direction change. Directional distances are measured according to the minimum number of direction changes required to reach each part of the street network. Here, red stands for 0 direction changes; dark blue stands for 6 direction changes.

5.4: Calculation of mean directional distance from a sample position, applying equation 1. Similar calculations are performed automatically from all line segments of the street network. In order to compute the 'network mean' of all the 'line segment means', each line segment mean is weighted by the length of the line segment. In this particular case we would have: $3.0391 \times 69.1809 = 210.2477$. The sum of all such weighted line segment means is then divided by the street network length as per equation 2. In complex networks these calculations must be computed for each of the unique syntactic conditions. In regular grids there are only a limited number of syntactic conditions and we can save time by producing formulae that describe grids of a particular type.

Figures 6 and 7 show the variation of the measures for regular grids where $1 \leq x \leq 100$ and $x=y$. However, for Figure 6: $m=n=100$ meters; while for Figure 7: $m=274$ meters and $n=80$ meters. Thus, Figure 6 represents a grid with square blocks and Figure 7 a grid with Manhattan blocks.

For the square grid, street length, l_x , increases linearly according to the number of intervals and total street length, L , increases according to the

square of the number of intervals; mean directional distance, D , for the system as a whole starts at 1 and tends to a limit of 1.5, reaching 1.4 already when the number of intervals is as small as 9.

With the Manhattan grid, the length of streets in the x-direction increases much faster than the length of streets in the y-direction, even though total street length increases, again, according to the square of the number of intervals. Mean directional distance is

smaller for a random position lying on streets in the y-direction (less than 1.25 as the number of intervals grows large) than it is for a random position lying on streets in the x-direction (less than 1.8 as the number of intervals grows large). Mean directional distance for the system as a whole, D , tends to 1.66. Thus, the elongation of blocks causes a differentiation of directional distance according to whether streets are aligned with the x-axis or the y-axis and

an increase in the mean directional distance for the system as a whole, compared to the square grid. Mean directional distance is greater for the longer streets, rather than the shorter ones, because the former have a greater proportion of total street length two direction changes away compared to the latter. Notice, furthermore, how the mean directional distance for the system as a whole corresponds to

Figure 6 (left):

Street length and directional distance for a regular square grid 100 x 100 meters.

6.1: The length of individual streets increases with the number of intervals.

6.2: The total length of the grid increases with the number of intervals.

6.3: As the number of intervals increases, the grid mean of the mean directional distances tends to a limit-value.

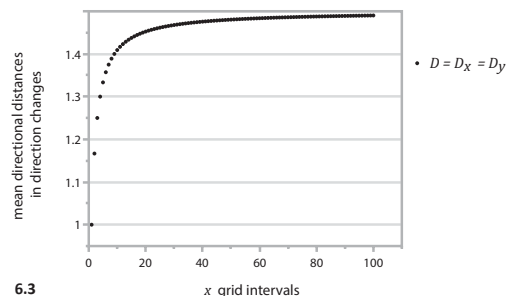
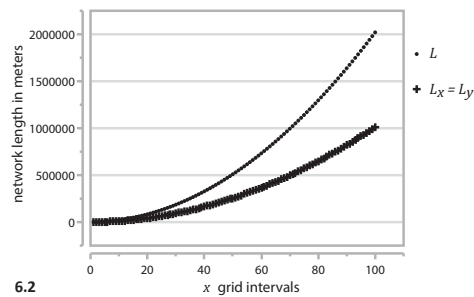
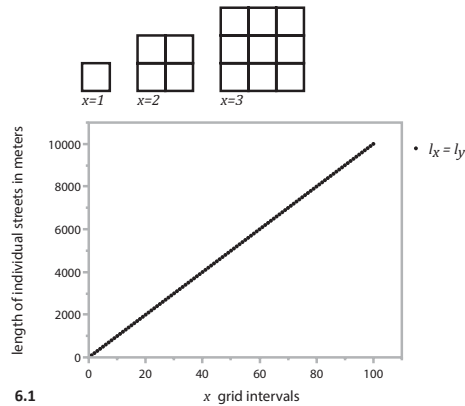


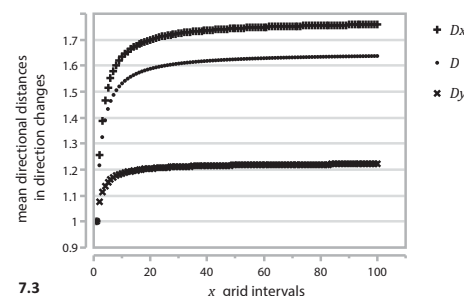
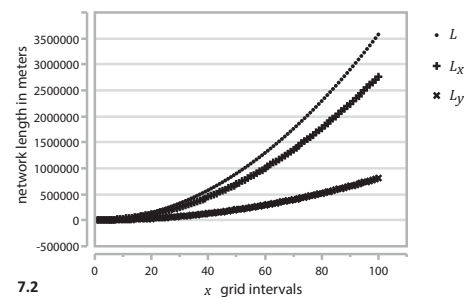
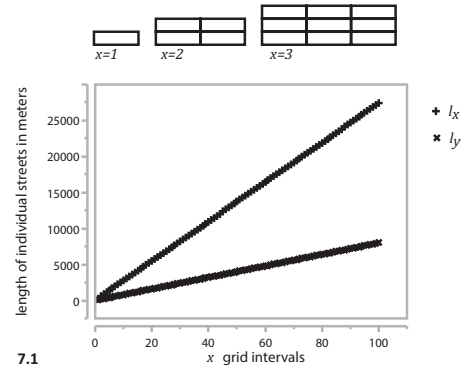
Figure 7 (right):

Street length and directional distance for a regular oblong grid 274 x 80 meters.

7.1: The length of individual streets increases with the number of intervals, at different rates in the x and the y directions.

7.2: The total length of the grid increases with the number of intervals, at different rates in the x and the y direction.

7.3: As the number of intervals increases, the grid mean of the mean directional distances tends to a limit-value for the grid as a whole, as well as for streets in the x and the y direction considered separately.



no actually available position but is rather a convenient theoretical characterization of the system. The important thing is that, in regular grids, whether square or not, directional distance tends to a particular limiting value, and the rate of increase is relatively flat as soon as the number of intervals reaches about 20. The cognitive stability of our understanding of a “grid” encompasses this property: We can build stable expectations of how many turns away things are, even though metric distances can grow indefinitely as the number of intervals and the interval length increase. In fact, in a regular grid, all spaces are within 2 direction changes from any position, so mean directional distance varies about 1.5 depending on the metric proportions of the grid and the choice of position along a long or a short street.

3. Regular grid with nested local streets: Spinning wheel

We will now proceed to present four grids with different syntaxes of local minor streets inserted within regular grids of major streets. In our first example, we nest a spinning wheel of short streets within each of the blocks of the primary regular grid. By translating the same spinning wheel horizontally and vertically to fill all blocks defined by the primary grid, we ensure that all junctions between major and minor streets are T-junctions and, consequently that the length of minor streets stays constant as the number of major intervals in either direction grows. A syntactically important consequence is that each of the original blocks contains an internal local street pattern that is not connected to other local street patterns except through the original grid of major streets. Thus, a clear distinction emerges between minor streets and local areas on the one hand, and major streets and global connections on the other hand. The network is exemplified in Figure 8.1.

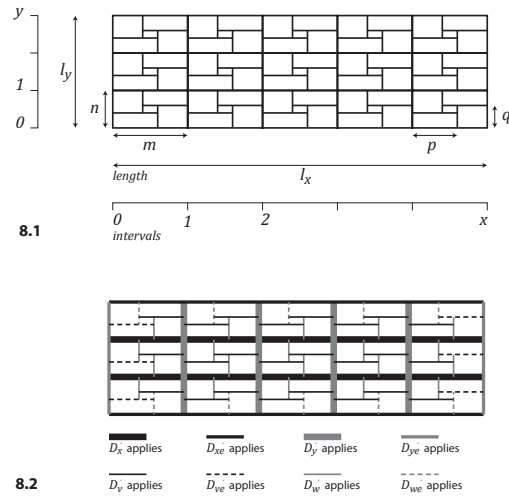


Figure 8:

8: Regular street grid with nested local streets.

8.1: Specification parameters.

8.2: Conditions relative to directional distance.

The system is defined by the following parameters: x and y are the number of major intervals between intersections of the primary grid, and m and n are the dimensions of these intervals respectively. The length of minor streets in the x-direction is p and the length of minor streets in the y-direction is q .

The following measures describing this network are defined:

L' is the total street length in the system.

l'_x is the length of a major street in the x-direction.

l'_y is the length of a major street in the y-direction.

L'_x is the total street length of major streets in the x-direction.

L'_y is the total street length of major streets in the y-direction.

L'_v is the total length of minor streets in the x-direction.

L'_w is the total length of minor streets in the y-direction.

For this system there are 8 different syntactic conditions regarding directional distance, due to the differentiation of major and minor streets and due to the presence or absence of edge-effects whereby the directional distances from street segments that are edges or are associated with edges are different from the directional distances from street segments in the interior of the system. This is shown in Figure 8.2.

D'_x is the mean directional distance from a random position on a major street which is not an edge in the x-direction.

D'_{xe} is the mean directional distance from a random position on a major street which is an edge in the x-direction.

D'_v is the mean directional distance from a random position on a minor street which is not subject to edge effects in the x-direction.

D'_{ve} is the mean directional distance from a random position on a minor street which is subject to edge effects in the x-direction.

D'_y is the mean directional distance from a random position on a major street which is not an edge in the y-direction.

D'_{ye} is the mean directional distance from a random position on a major street which is an edge in the x-direction.

D'_w is the mean directional distance from a random position on a minor street which is not subject to edge effects in the y-direction.

D'_{we} is the mean directional distance from a random position on a minor street which is subject to edge effects in the y-direction.

D' is the mean of means of directional distance for the system as a whole, taking into account the proportional distribution of the various conditions over the street network.

The following equations describe these measures as a function of the parameters when $x > 1$ and $y > 1$:

$$L' = x(y+1)m + y(x+1)n + 2xy(p+q) \quad (11)$$

$$l'_x = xm \quad (12)$$

$$l'_y = yn \quad (13)$$

$$L'_x = x(y+1)m \quad (14)$$

$$L'_y = y(x+1)n \quad (15)$$

$$L'_v = 2yxp \quad (16)$$

$$L'_w = 2yxq \quad (17)$$

$$D'_x = \frac{-4qx + ny + 2mxy + nxy + 4pxy + 6qxy}{L} \quad (18)$$

$$D'_{xe} = \frac{-2qx + ny + 2mxy + nxy + 4pxy + 6qxy}{L} \quad (19)$$

$$D'_v = \frac{-4p - 4q + 2mx + ny - 4py + 2mxy + 3nxy + 8pxy + 6qxy}{L} \quad (20)$$

$$D'_{ve} = \frac{4p - 4q + 2mx + ny - 2py + 2mxy + 3nxy + 8pxy + 6qxy}{L} \quad (21)$$

$$D'_y = \frac{mx - 4py + mxy + 2nxy + 6pxy + 4qxy}{L} \quad (22)$$

$$D'_{ye} = \frac{mx - 2py + mxy + 2nxy + 6pxy + 4qxy}{L} \quad (23)$$

$$D'_w = \frac{-4p - 4q + mx - 4qx + 2ny + 3mxy + 2nxy + 6pxy + 8qxy}{L} \quad (24)$$

$$D'_{we} = \frac{-4p - 4q + mx - 2qx + 2ny + 3mxy + 2nxy + 6pxy + 8qxy}{L} \quad (25)$$

$$D' = \frac{D'_x(l'_x - 2xm) + D'_y(l'_y - 2yn) + D'_{xe}(2xm) + D'_{ye}(2yn) + D'_v(2xy - 2y)p + D'_w(2xy - 2x)q + D'_{ve}(2yp) + D'_{we}(2xq)}{L} \quad (26)$$

Figures 9 and 10 show the variation of the measures for grids where $1 < x \leq 100$ and $x=y$. For Figure 9: $m=n=180$ meters and $p=q=120$ meters; while for Figure 10: $m=354$ meters, $n=240$ meters,

$p = 274$ meters and $q = 160$ meters. The following is observed: The length of major streets increases with the increase in grid intervals but the length of minor streets stays constant. Nevertheless, the aggregate contribution of the minor streets to the total street length is comparable and a little greater than the contribution of the major streets (Figures 9.2 and 10.2). Furthermore, the mean directional distance associated with minor streets is considerably higher

than the mean directional distance associated with major streets, by about one direction change. Thus, we can talk about the internal differentiation of scales in two ways, first in terms of street length, and second in terms of a polarization of directional distance. In regular systems such as the one now considered, the relationship of directional distances becomes stable after about 20 grid intervals and seems an effective way to characterize the system.

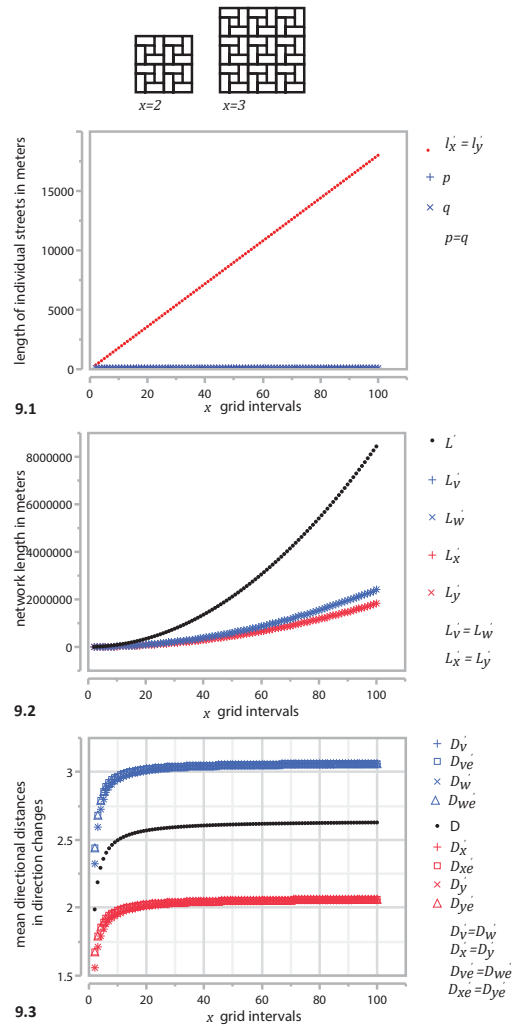


Figure 9 (left):

Street length and directional distance for a regular square street grid with nested local streets; $m = n = 180$ meters; $p = q = 120$ meters.

9.1 The length of individual major streets (red) increases with the number of intervals. The length of minor streets (blue) stays constant.

9.2: The total length of the grid increases with the number of intervals (black), at different rates for major (red) and minor (blue) streets.

9.3: As the number of intervals increases, the grid mean of the mean directional distances tends to a limit-value (black). The mean directional distances associated with major streets (red) tend to a lower value (red) than the mean directional distances associated with minor streets (blue).

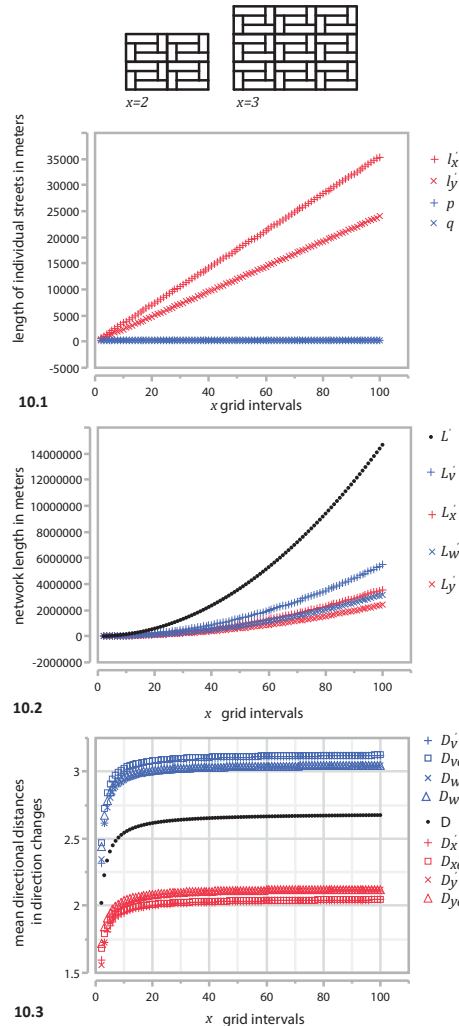


Figure 10 (right):

Street length and directional distance for a regular oblong grid with nested local streets; $m = 354$ meters, $n = 240$ meters, $p = 274$ meters, $q = 160$ meters.

10.1: The length of individual major streets increases with the number of intervals, at different rates in the x and the y directions. The length of minor streets stays constant

10.2: The total length of the grid increases with the number of intervals (black), at different rates for major (red) and minor (blue) streets in the x and the y direction.

10.3: As the number of intervals increase, the

(Figure 10, right)

grid mean of the mean directional distances tends to a limit-value for the grid as a whole (black), as well as for major (red) or minor (blue) streets in the x and y directions considered separately.

Figure 11:

Comparison of exact and approximate mean directional distance values for a regular grid with nested spinning wheel, as computed by equations 26 for D' and 27 for D'_{alt} .

11.1: Analysis of the 180m by 180m grid.

11.2: Analysis of the 354m by 240m grid.

Given the sharp differentiation of scales of organization, the system can usefully be considered as a relationship between two parts: a regular skeleton grid on the one hand, and local area inserts on the other. The question becomes how to express this intuitive insight mathematically in a useful way. Let equations 8, 9 and 10, above, represent the directional distances associated with the skeleton grid, without considering the local area inserts. Also let d stand for the mean directional distance of minor streets from the nearest major street – in the system considered $d = 1$. Furthermore, let the difference between edge conditions and typical conditions be ignored. The major directional distance relationships can be re-written as follows:

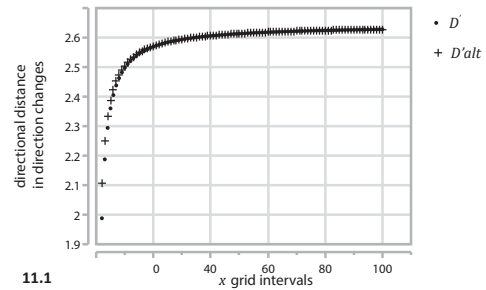
$$D'_{alt} = \frac{\left(\frac{D(L_x + L_y) + (D + d)(L_v + L_w)}{L} \right) (L_x + L_y) + \left(\frac{(D + d)(L_x + L_y) + (D + 2d)(L_v + L_w)}{L} \right) (L_v + L_w)}{L} \quad (27)$$

Where d is the mean directional distance from each minor street to the nearest major street.

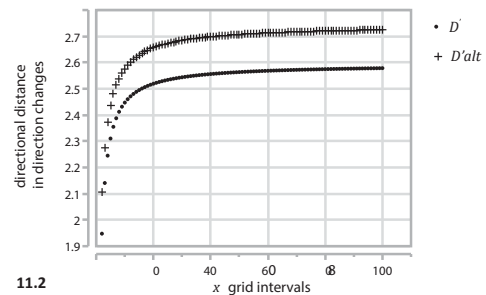
The approximation of the values computed based on this formula and the values computed based on formula 27 is very good for reasonably large numbers of intervals, as shown in Figure 11. The approximation is almost perfect for the square grid, with hardly any deviation for $x > 10$; the deviation between the two formulae is of the order of a decimal for the 354m by 240m grid.

The idea of decomposing directional distances in this way is rather important because it recognizes the relative independence of scales of organization and of the way in which they are designed in practice. Of course, this particular decomposition is particularly effective when the local areas cannot communicate with each other except through the major streets. The radical alternative to this condition

is when the super blocks of a grid of major streets are subdivided by narrower streets that align across superblocks to acquire the same length as the major streets. This is briefly discussed below.



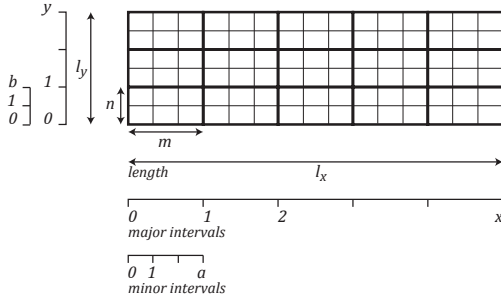
11.1



11.2

4. Regular grid inserted within regular supergrid

In our second example, narrower streets are inserted within a regular grid of major streets such as described in Figure 4, such that the number of x intervals is multiplied by a and the number of y intervals by b , with a concomitant reduction of m and n interval distances reduced according to the ratios m/a and n/b , as shown in Figure 12. In this case, equations 3, 6-10 are modified as show in equations 28-33 below; these equations revert to their original form when we set $a=b=1$. Of course, since for large numbers of intervals the mean directional distance for a grid gets close to a limiting value, the addition of inserted minor street grids does not affect such distances.



$$L = x(by + 1)m + y(ax + 1)n \quad (28)$$

$$L_x = x(by + 1)m \quad (29)$$

$$L_y = y(ax + 1)n \quad (30)$$

$$D_x = \frac{(ax+1)yn+2bxym}{L} \quad (31)$$

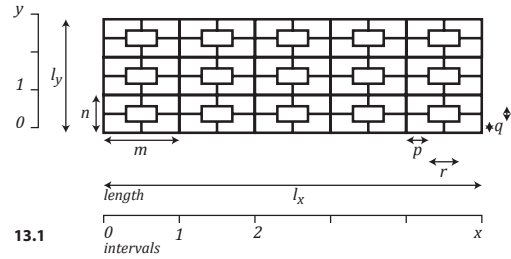
$$D_y = \frac{(by+1)xm+2axyn}{L} \quad (32)$$

$$D = \frac{D_x L_x + D_y L_y}{L} \quad (33)$$

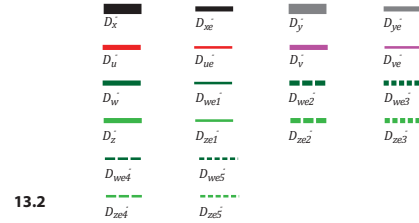
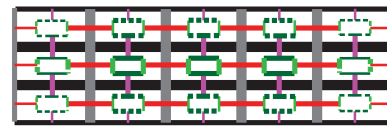
5. Regular grid with nested local streets: Central blocks

In the third example, a central block is placed within each of the original blocks of a primary regular grid, with four streets leading towards it from the center of the major street intervals. The arrangement implies that minor streets cross the major streets. They remain, however, short, as they are interrupted by the central blocks on which they are incident at both ends. From the point of view of directional distance, the shortest paths from one local area to another which is not in an adjacent superblock are through the system of major streets. Thus, a clear distinction is preserved between minor streets and local areas,

on the one hand, and major streets on the other. The system is defined by the following parameters: x and y are the number of major intervals between intersections of the primary grid, and m and n are the dimensions of these intervals respectively. The lengths of minor streets incident on the central blocks in the x -direction and y -direction are p and q respectively. The length of the minor streets at the edges of the central block in the x -direction and the y -direction are r and t respectively. The network is exemplified and parameters are graphically defined in Figure 13.1.



13.1



13.2

Figure 12 (left):

Regular grid of major streets and inserted regular grid of minor streets, with specification parameters.

Figure 13 (right):

Regular street grid with nested central blocks.

13.1: Specification parameters.

13.2: Conditions relative to directional distance.

The following measures describing this network are defined:

L'' is the total street length in the system.

l_x'' is the length of a major street in the x -direction.

l_y'' is the length of a major street in the y -direction.

L_x'' is the total street length of major streets in the x -direction.

L_y'' is the total street length of major streets in the y-direction.

L_u'' is the total length of minor streets incident on central blocks in the x-direction.

L_v'' is the total length of minor streets incident on central blocks in the y-direction.

L_w'' is the total length of minor streets at the edge of central blocks in the x-direction.

L_z'' is the total length of minor streets at the edge of central blocks in the y-direction.

In this case there are 20 different syntactic conditions relative to directional distances, as shown in Figure 13.2. In the interest of brevity we will not extend the graphic definition by a discursive description. The following equations describe these measures as a function of the parameters when $x > 2$ and $y > 2$:

$$L'' = x(y+1)m + y(x+1)n + 2xy(p+q+r+t) \quad (34)$$

$$l_x'' = xm \quad (35)$$

$$l_y'' = yn \quad (36)$$

$$L_x'' = x(y+1)m \quad (37)$$

$$L_y'' = y(x+1)n \quad (38)$$

$$L_u'' = 2yxp \quad (39)$$

$$L_v'' = 2yxq \quad (40)$$

$$L_w'' = 2yxr \quad (41)$$

$$L_z'' = 2yxt \quad (42)$$

$$D_x'' = \frac{-4qx-4rx+ny+2mxy+nxy+4pxy+6qxy+8rxy+6txy}{L} \quad (43)$$

$$D_{xe}'' = \frac{-2qx-2rx+ny+2mxy+nxy+4pxy+6qxy+8rxy+6txy}{L} \quad (44)$$

$$D_y'' = \frac{mx-4py-4ty+mxy+2nxy+6pxy+4qxy+6rxy+8txy}{L} \quad (45)$$

$$D_{ye}'' = \frac{mx-2py-2ty+mxy+2nxy+6pxy+4qxy+6rxy+8txy}{L} \quad (46)$$

$$D_u'' = \frac{-4p-8r-8t+2mx+ny-4py-4ty+2mxy+3nxy+8pxy+6qxy+8rxy+10txy}{L} \quad (47)$$

$$D_{ue}'' = \frac{-2p-4r-4t+2mx+ny-2py-2ty+2mxy+3nxy+8pxy+6qxy+8rxy+10txy}{L} \quad (48)$$

$$D_v'' = \frac{-4q-8r-8t+mx-4qx-4rx+2ny+3mxy+2nxy+6pxy+8qxy+10rxy+8txy}{L} \quad (49)$$

$$D_{ve}'' = \frac{-2q-4r-4t+mx-2qx-2rx+2ny+3mxy+2nxy+6pxy+8qxy+10rxy+8txy}{L} \quad (50)$$

$$D_w'' = \frac{-8p-8q-18r-16t+2mx-4qx-4rx+3ny+4mxy+3nxy+8pxy+10qxy+12rxy+10txy}{L} \quad (51)$$

$$D_{we1}'' = \frac{-6p-8q-16r-14t+2mx-4qx-4rx+3ny+4mxy+3nxy+8pxy+10qxy+12rxy+10txy}{L} \quad (52)$$

$$D_{we2}'' = \frac{-8p-6q-16r-16t+2mx-4qx-4rx+3ny+4mxy+3nxy+8pxy+10qxy+12rxy+10txy}{L} \quad (53)$$

$$D_{we3}'' = \frac{-8p-6q-14r-12t+2mx-2qx-2rx+3ny+4mxy+3nxy+8pxy+10qxy+12rxy+10txy}{L} \quad (54)$$

$$D_{we4}'' = \frac{-6p-6q-14r-14t+2mx-4qx-4rx+3ny+4mxy+3nxy+8pxy+10qxy+12rxy+10txy}{L} \quad (55)$$

$$D_{we5}'' = \frac{-6p-12r-13t+2mx-2qx-2rx+3ny+4mxy+3nxy+8pxy+10qxy+12rxy+10txy}{L} \quad (56)$$

$$D_z'' = \frac{-8p-8q-16r-18t+3mx+2ny-4py-4ty+3mxy+4nxy+10pxy+8qxy+10rxy+12txy}{L} \quad (57)$$

$$D_{ze1}'' = \frac{-8p-6q-14r-16t+3mx+2ny-4py-4ty+3mxy+4nxy+10pxy+8qxy+10rxy+12txy}{L} \quad (58)$$

$$D_{ze2}'' = \frac{-6p-8q-16r-16t+3mx+2ny-4py-4ty+3mxy+4nxy+10pxy+8qxy+10rxy+12txy}{L} \quad (59)$$

$$D_{ze3}'' = \frac{-6p-8q-12r-14t+3mx+2ny-2py-2ty+3mxy+4nxy+10pxy+8qxy+10rxy+12txy}{L} \quad (60)$$

$$D_{ze4}'' = \frac{-6p-6q-14r-14t+3mx+2ny-4py-4ty+3mxy+4nxy+10pxy+8qxy+10rxy+12txy}{L} \quad (61)$$

$$D_{ze5}'' = \frac{-6q-13r-12t+3mx+2ny-2py-2ty+3mxy+4nxy+10pxy+8qxy+10rxy+12txy}{L} \quad (62)$$

Because of the number of terms needed to describe all syntactic conditions involved, the equation for D'' cannot conveniently be written in the same expanded form as equation 26 for D' . Thus, we first provide the equations for the total street lengths associated with each condition of directional distance. These are denoted by " L " and the suffix of the corresponding mean directional distance value.

$$L_{D_x''} = mx(y - 1) \quad (63)$$

$$L_{D_{xe}''} = 2mx \quad (64)$$

$$L_{D_y''} = ny(x - 1) \quad (65)$$

$$L_{D_{ye}''} = 2ny \quad (66)$$

$$L_{D_u''} = 2py(x - 1) \quad (67)$$

$$L_{D_{ue}''} = 2py \quad (68)$$

$$L_{D_v''} = 2qx(y - 1) \quad (69)$$

$$L_{D_{ve}''} = 2qx \quad (70)$$

$$L_{D_w''} = 2r(x - 2)(y - 2) \quad (71)$$

$$L_{D_{we1}''} = 4r(y - 2) \quad (72)$$

$$L_{D_{we2}''} = 2r(x - 2) \quad (73)$$

$$L_{D_{we3}''} = 2r(x - 2) \quad (74)$$

$$L_{D_{we4}''} = 4r \quad (75)$$

$$L_{D_{we5}''} = 4r \quad (76)$$

$$L_{D_z''} = 2t(x - 2)(y - 2) \quad (77)$$

$$L_{D_{ze1}''} = 4t(x - 2) \quad (78)$$

$$L_{D_{ze2}''} = 2t(x - 2) \quad (79)$$

$$L_{D_{ze3}''} = 2t(y - 2) \quad (80)$$

$$L_{D_{ze4}''} = 4t \quad (81)$$

$$L_{D_{ze5}''} = 4t \quad (82)$$

Given equations 63-82 the mean directional distances for all syntactic conditions are known and so are the street lengths to which each mean directional distance applies. Thus, equation 2 can be used with appropriate substitutions to obtain D'' , the mean of mean depths for this network type.

Figures 14 and 15 show the variation of the measures for grids where $2 < x \leq 100$ and $x = y$. For Figure 14: $m = n = 200$ meters, $p = q = 65$ meters and $r = t = 70$; while for Figure 15: $m = 500$ meters, $n = 220$ meters, $p = 200$ meters, $q = 75$ meters, $r = 100$ meters and $t = 70$ meters. The following is observed: the length of major streets increases with the increase in grid intervals but the length of minor streets stays constant. Nevertheless, the aggregate contribution of the minor streets to the total street length is comparable to the contribution of the major streets (Figures 14.2 and 15.2). Directional distances are clustered in three bands of values: the minor streets around the central blocks tend to mean directional distances over 4 turns, the minor streets incident to the central blocks tend to directional distances over 3 but less than 3.5 turns, and the major streets tend to directional distances between 2 and 2.5 turns (Figures 14.3 and 15.3). Thus, we can talk about the internal differentiation of scales in terms of street length and in terms of a polarization of directional distance as with the second example, except for the fact that here we have three rather than two bands of directional distance values.

This system can also be decomposed into a primary grid and local area inserts which have a given mean depth d from the primary grid. Here:

$$d = \frac{2(p + q) + 4(t + r)}{2(p + q + t + r)} \quad (83)$$

Peponis, J., Feng, C., Green, D., Haynie, D., Kim, S. H., Sheng, Q., Vialard, A. & Wang, H.

Figure 14 (left):

Street length and directional distance for a regular square street grid with nested central block; $m = n = 200$ meters; $p = q = 75$ meters, $r = t = 70$ meters.

14.1 The length of individual major streets (red) increases with the number of intervals. The length of minor streets (blue) stays constant.

14.2: The total length of the grid increases with the number of intervals.

14.3: As the number of intervals increases, the grid mean of the mean directional distances tends to a limit-value (black). The mean directional distances associated with major streets (red) tend to a lower value than the mean directional distances associated with minor streets. The latter are split in two groups, those associated with the perimeter of the central block (green) and those associated with the incident streets (blue).

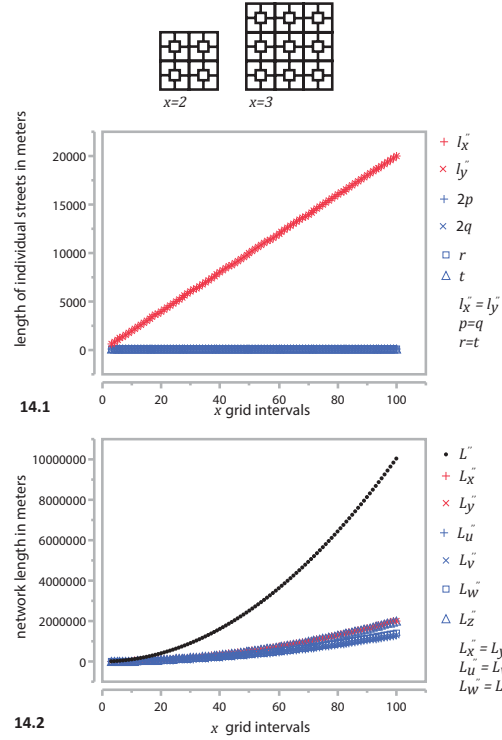


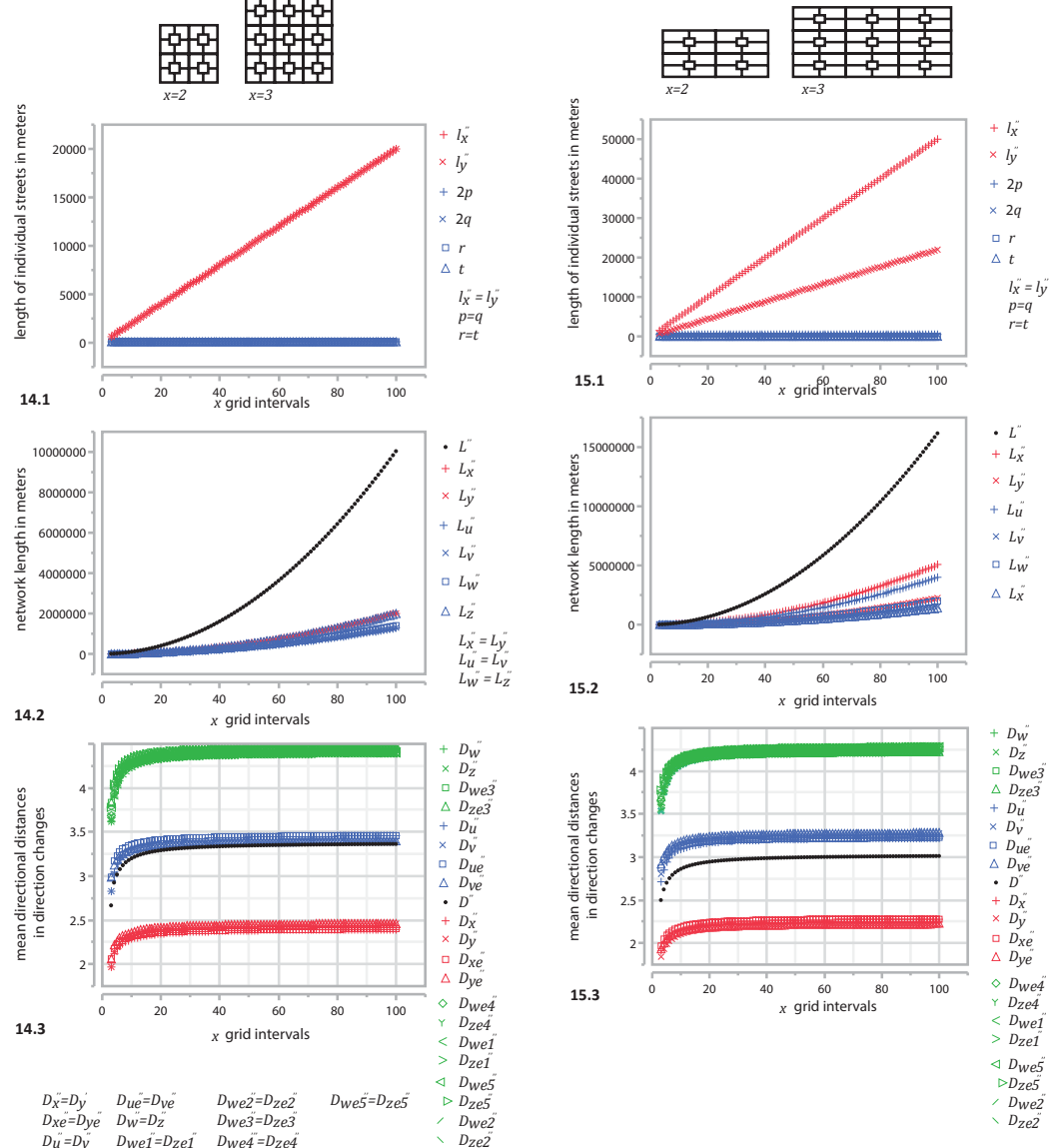
Figure 15 (right):

Street length and directional distance for a regular oblong street grid with nested central block; $m = 500$ meters; $n = 220$ meters; $p = 200$ meters; $q = 75$ meters, $r = 100$ meters; $t = 70$ meters.

15.1 The length of individual major streets (red) increases with the number of intervals. The length of minor streets (blue) stays constant.

15.2: The total length of the grid increases with the number of intervals.

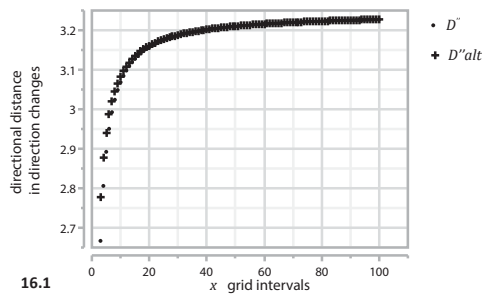
15.3: As the number of intervals increases, the grid mean of the mean directional distances tends to a limit-value (black). The mean directional distances associated with major streets



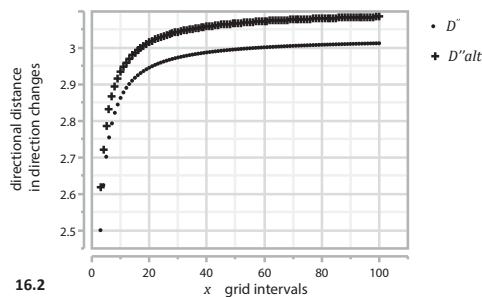
This value is inserted in formula 27, adjusted for the parameters of this system as follows:

$$D_{alt}'' = \frac{\left(\frac{D(L_x + L_y) + (D + d)(L_v + L_w + L_u + L_z)}{L} \right) (L_x + L_y) + \left(\frac{(D + d)(L_x + L_y) + (D + 2d)(L_v + L_w + L_u + L_z)}{L} \right) (L_v + L_w + L_u + L_z)}{L} \quad (84)$$

The results obtained are very good approximations of D'' , as shown in Figure 16. Thus, the idea of decomposition of directional distance into components is applicable to this example as to the second presented above. Applicability is made possible by the fact that there are no inserted streets that traverse superblocks from edge to edge to align across them. The distinction between supergrid and local areas remains clear.



16.1

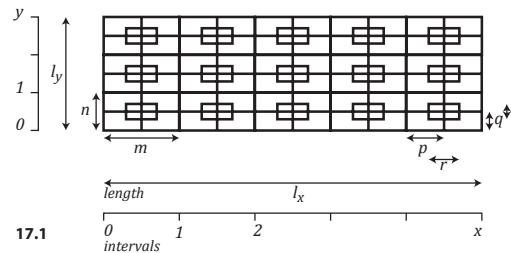


16.2

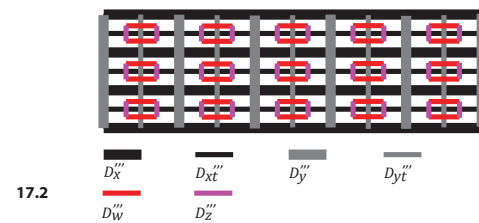
6. Regular grid with nested local streets: Central blocks with traversing streets

Our final theoretical example is identical to the preceding one except that the streets previously incident to the central block now run through it. Thus, the only streets which are minor from the point of view of street length are the ones surrounding the central block. The system and parameters are presented in Figure 17. In this case, $p=m/2$ and $q=n/2$. There are only 6 syntactic conditions, the original

major streets, the inserted traversing streets and the minor streets, in the x and y-directions respectively.



17.1



17.2

L''' is the total street length in the system.

L_x''' is the length of a major street in the x-direction.

L_y''' is the length of a major street in the y-direction.

L_x''' is the total street length of major streets in the x-direction.

L_y''' is the total street length of major streets in the y-direction.

L_u''' is the total length of streets traversing central blocks in the x-direction.

L_v''' is the total length of streets traversing central blocks in the y-direction.

L_w''' is the total length of minor streets at the edge of central blocks in the x-direction.

L_z''' is the total length of minor streets at the edge of central blocks in the y-direction.

D_x''' is the mean directional distance from a major street in the x-direction.

D_y''' is the mean directional distance from a major street in the y-direction.

D_{xt}''' is the mean directional distance from a traversing street in the x-direction.

(Figure 15, right):

(red) tend to a lower value than the mean directional distances associated with minor streets. The latter are split in two groups, those associated with the perimeter of the central block (green) and those associated with the incident streets (blue).

Figure 16 (left):

Comparison of exact and approximate mean directional distance values for a regular grid with nested central block, as computed by equations 2 for D'' and 84 for D''_{alt} . 16.1: Analysis of the 200m by 200m grid. 16.2: Analysis of the 500m by 220m grid.

Figure 17 (right):

Regular street grid with nested central blocks and traversing streets.

17.1: Specification parameters.

17.2: Conditions relative to directional distance.

D_{yt}''' is the mean directional distance from a traversing street in the y-direction.

D_w''' is the mean directional distance from a minor street in the x-direction.

D_y''' is the mean directional distance from a minor street in the y-direction.

D''' is the mean of means of directional distance for the network as a whole.

These variables are computed by the following equations:

$$L''' = x(2y + 1)m + y(2x + 1)n + 2xy(r + t) \quad (85)$$

$$l_x''' = xm \quad (86)$$

$$l_y''' = yn \quad (87)$$

$$L_x''' = x(y + 1)m \quad (88)$$

$$L_y''' = y(x + 1)n \quad (89)$$

$$L_{xt}''' = xym \quad (90)$$

$$L_{yt}''' = yxn \quad (91)$$

$$L_w''' = 2yxr \quad (92)$$

$$L_z''' = 2yxt \quad (93)$$

$$D_x''' = \frac{ny + 4mxy + 2nxy + 4rxy + 6txy}{L} \quad (94)$$

$$D_y''' = \frac{mx + 2mxy + 4nxy + 6rxy + 4txy}{L} \quad (95)$$

$$D_{xt}''' = \frac{-4tx + ny + 4mxy + 2nxy + 4rxy + 6txy}{L} \quad (96)$$

$$D_{yt}''' = \frac{mx - 4ry + 2mxy + 4nxy + 6rxy + 4txy}{L} \quad (97)$$

$$D_w''' = \frac{-2r - 4t + 2mx + ny - 4ry + 4mxy + 6nxy + 8rxy + 6txy}{L} \quad (98)$$

$$D_z''' = \frac{-4r - 2t + mx - 4tx + 2ny + 6mxy + 4nxy + 6rxy + 8txy}{L} \quad (99)$$

$$D''' = \frac{D_x'''x(y+1)m + D_y'''y(x+1)n + D_{xt}'''xym + D_{yt}'''xyn + D_w'''2xyr + D_z'''2xyt}{L} \quad (100)$$

Figures 18 and 19 show the variation of the measures for grids where $1 < x \leq 100$ and $x = y$. For Figure 18: $m = n = 280$ meters and $r = t = 140$ meters; while for Figure 19: $m = 560$ meters, $n = 280$ meters, $r = 200$ meters and $t = 120$ meters. The following is observed: the length of major streets as well as inserted traversing streets increases with the increase in grid intervals but the length the minor streets surrounding the central blocks stays constant. The aggregate contribution of the minor streets to the total street length is similar to the contribution of the long streets (Figures 18.2 and 19.2). Directional distances are clustered in two bands of values: the minor streets around the central blocks tend to mean directional distances between 2.5 and 3 turns, while the long streets tend to directional distances between 1.5 and 2.00 turns (Figures 18.3 and 19.3).

Because the traversing streets of this network are aligned, no strict distinction can be made between the supergrid and the local areas. Thus, the decomposition according to formula 27 (or its adjustment as formula 84) would not work. If all long streets are treated as part of a supergrid and if, consequently, only the short streets surrounding the central blocks are treated as local, then some approximation of the mean directional distance of

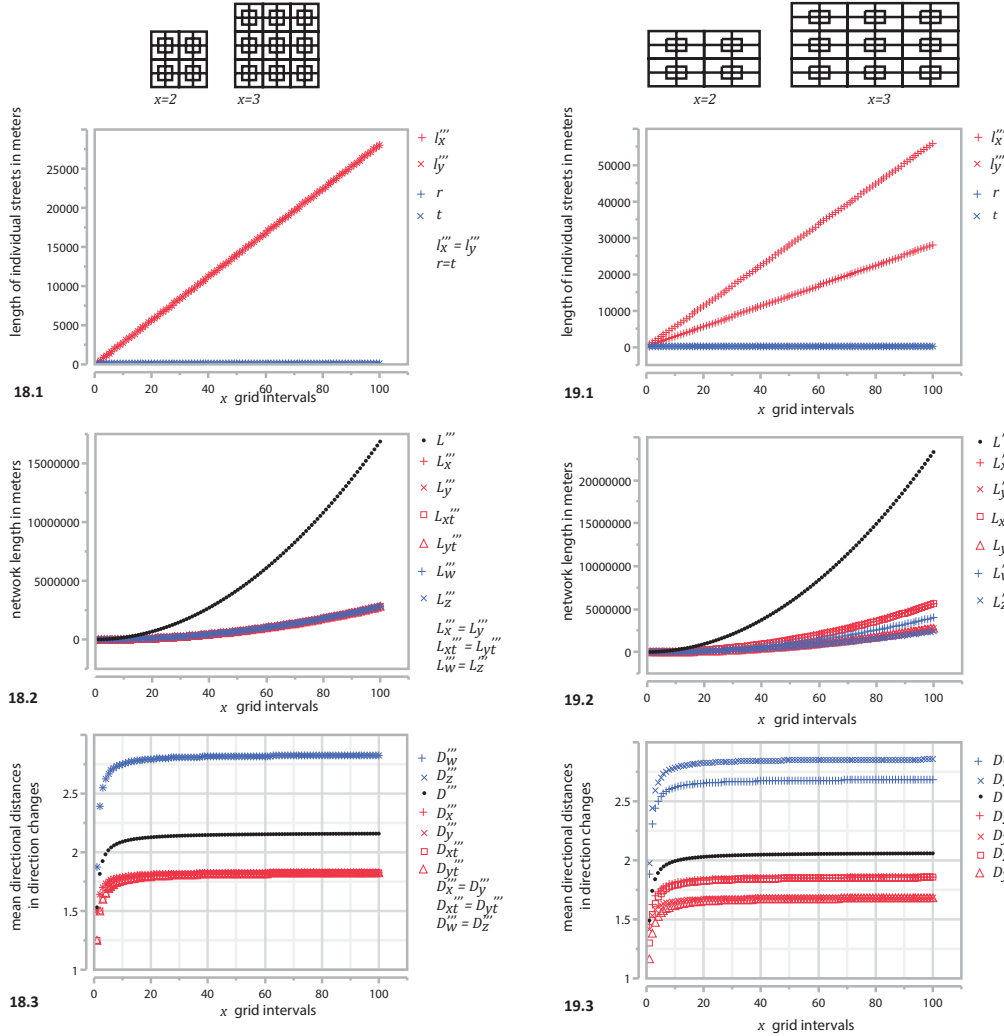


Figure 18 (left):

Street length and directional distance for a regular square street grid with nested central blocks and traversing streets; $m = n = 280$ meters; $r = t = 140$ meters.

18.1 The length of individual major streets (red) increases with the number of intervals. The length of minor streets around the central block (blue) stays constant.

18.2: The total length of the grid increases with the number of intervals.

18.3: As the number of intervals increases, the grid mean of the mean directional distances tends to a limit-value (black). The mean directional distances associated with major streets and traversing minor streets (red) tend to a lower value than the mean directional distances associated with minor streets around the central block (blue).

Figure 19 (right):

Street length and directional distance for a regular oblong street grid with nested central blocks and traversing streets; $m = 560$; $n = 280$ meters; $r = 200$ meters; $t = 120$ meters.

19.1 The length of individual major streets (red) increases with the number of intervals. The length of minor streets around the central block (blue) stays constant.

19.2: The total length of the grid increases with the number of intervals.

19.3: As the number of intervals increases, the grid mean of the mean directional distances tends to a limit-value (black). The mean directional distances associated with major

the network can be applied by the following new adjustment of formula 27, with $d=1$:

$$D_{alt}''' = \frac{\left(\frac{D(L_x + L_y + L_{xt} + L_{yt}) + (D + d)(L_w + L_z)}{L} \right) (L_x + L_y + L_{xt} + L_{yt}) + \left(\frac{(D + d)(L_x + L_y + L_{xt} + L_{yt}) + (D + 2d)(L_z + L_w)}{L} \right) (L_w + L_z)}{L} \quad (101)$$

Figure 19 (right):

streets and traversing minor streets (red) tend to a lower value than the mean directional distances associated with minor streets around the central block (blue).

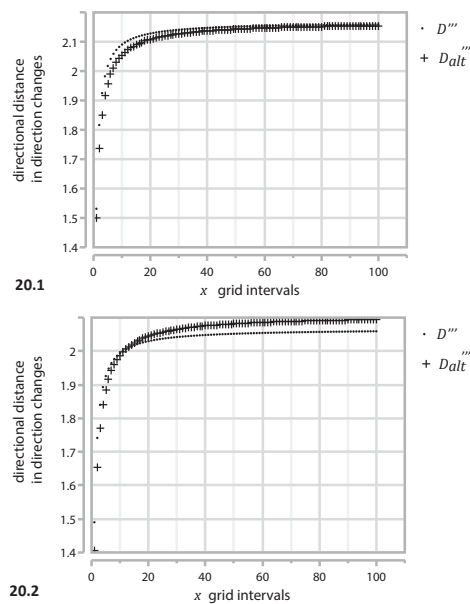
Figure 20 :

Comparison of exact and approximate mean directional distance values for a regular grid with nested central blocks and traversing streets, as computed by equations 2 for D''' and 101 for D'''_{alt}

20.1: Analysis of the 280m by 280m grid.

20.2: Analysis of the 560m by 280m grid.

The results obtained are good approximations of D''' , as shown in Figure 20.



7. The four theoretical nested systems: lessons and observations

The analysis of the four theoretical nested systems clarifies two methodological ideas and leads to two substantive theoretical insights, one already stated explicitly and one remaining to be clarified here.

The first methodological idea bears on the notion of a *syntactic condition*, which applies to all spaces in a system which are identical from the point of view of a syntactic measure. In regular street networks, the number of syntactic conditions is much smaller than the number of elements, whether by elements we mean line segments or street segments – a street segment links two street intersections with at least 3 incident streets each, and can comprise multiple line segments. The idea of a *syntactic condition* is implicit in the foundations of space syntax but tends to be underemphasized when the examples studied are historically grown systems where each

“element” appears as a unique syntactic condition relative to a syntactic measure. One advantage of studying hypothetical regular systems is that syntactic conditions become easy to identify.

The methodological idea of *syntactic conditions* is linked to the first substantive theoretical insight belabored through the preceding analysis: In certain systems, a clear pattern of *differentiation of scale* is observed. Short streets link up to form local areas inserted within a network of long streets. This leads to a polarization of mean directional distance values, with low values associated with the long streets and high values associated with the short streets. The underlying idea is familiar from the earlier work of Hillier (2002).

The second methodological idea is intended to capture the implications of the *differentiation of scales* by expressing in a new way the idea of mean directional distance. We have shown that the mean directional distance of a system can sometimes be approximated by distinguishing two components. First, the mean directional distance associated with the supergrid as an independent system; second the mean directional distance of the minor streets of nested areas from the nearest supergrid space. This *decomposition* is a fundamental technical step which resonates with design intuition: it makes sense to design the supergrid and the nested areas as distinct and interacting systems. The larger lesson is that we sometimes must reconsider the logic of computation from the point of view of conceptualization, rather than only look at the numerical outputs of the computation.

The second substantive theoretical insight can now be introduced. A range of syntactic conditions relative to some set of syntactic measures is not equivalent to a characterization of the *syntactic principles* that characterize a system. The four theoretical nested systems studied are associated with distinct syntactic principles which can now be clarified. For this, we refer to the diagram in Figure

21. In the top two examples, the nested areas are not strongly localized because there are streets spanning the whole network – in the case of the diagram at the top left, all streets span the whole

network and are presumed to be differentiated from the supergrid only by width and perhaps zoning and development densities. In the bottom two examples, the nested areas are strongly localized.

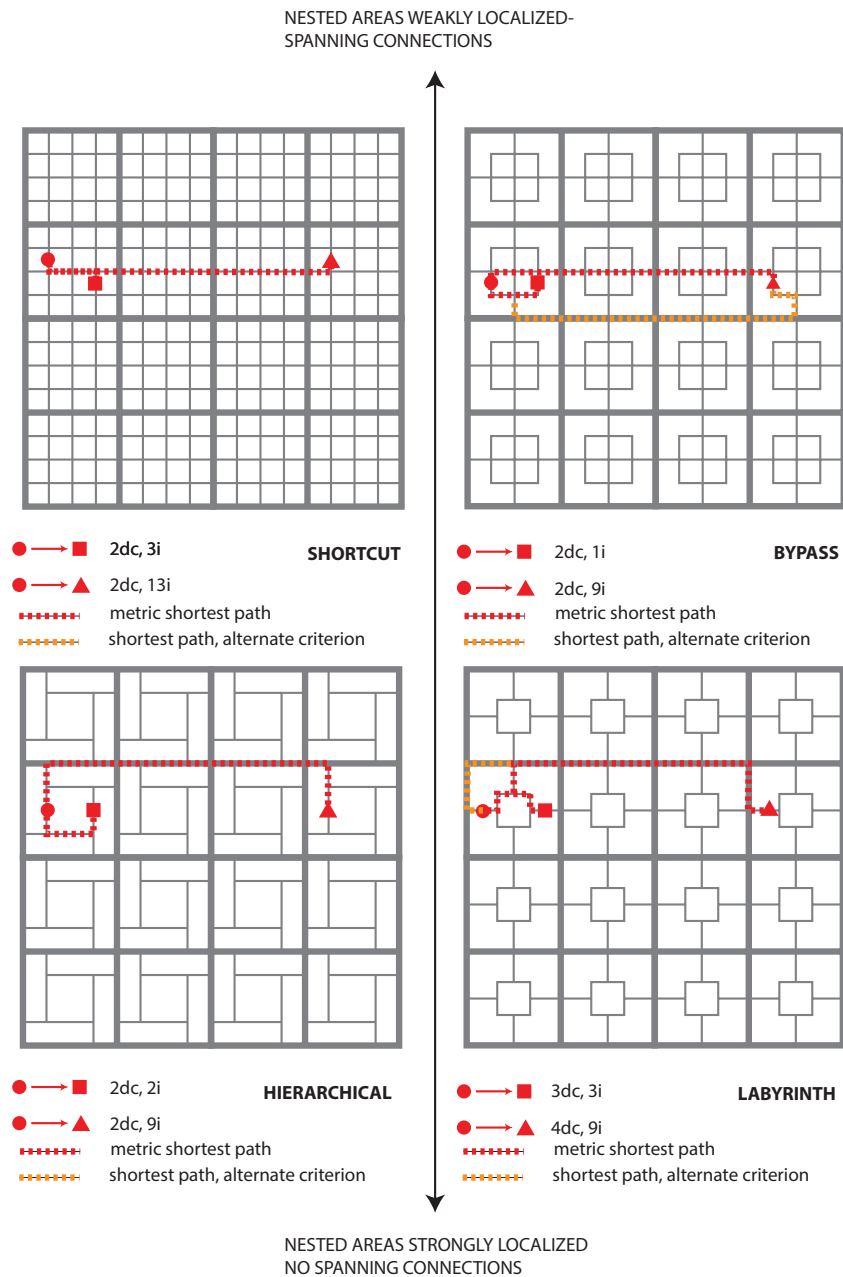


Figure 21 :

Alternative syntactic principles for nesting local areas in supergrid systems.

Over and above this distinction, each of the diagrams exemplifies specific syntactic principles. The top left always allows shortcuts: the paths with shortest length or fewest direction changes do not need to go through the supergrid. The top right allows for paths that have shortest length and fewest direction changes to be independent of the supergrid. However, the paths through the supergrid are often shortest according to the number of intersections traversed. Thus, the supergrid bypasses some of the density of connections and, possibly, enables faster movement. The bottom right is organized in such a way that even local connections can be made through paths that involve fewer direction changes by using the supergrid, instead of using internal connections. Traversing the local areas in pursuit of paths of shortest length adds cost in terms of direction changes, much as in many housing estates studied in London in the early years of development of space syntax. Finally, the diagram at the bottom left is hierarchical in that paths inside local areas are always shorter, by length as well as direction changes, but shortest paths across local areas always involve the supergrid.

With these insights about the behavior of networks comprising supergrids and local systems of nested streets, we now return to the study of the examples referred to in the first section of this paper.

8. An analysis of six urban layouts

We characterize each area by a number of syntactic measures while explaining the significance of each measure and the question that is being addressed. The analysis, presented in Table 2 below, is based on a version of *Spatialist_lines* developed on a Grasshopper platform by Chen Feng, as part of a collaborative project between the Georgia Institute of Technology and Perkins + Will. The conceptual foundations of the analysis are described by Peponis, Bafna and Zhang (2008). In what follows, all measures are normalized by street length. In other

words, we consider the system as made up of a given length of streets, rather than think of it as comprised of a given number of discrete elements. In all analyses, the parametric threshold for counting a direction change is set at 15°.

Degree of approximation to a regular grid: In a regular grid all parts of the street network are accessible within two direction changes from any randomly chosen location. Thus, the proportion of street length that is accessible within two direction changes from a random location in the areas under study is a measure of how far they approximate a regular grid. This is offered in the first data row of the table. Of course, Chicago stands out as having 90% of street length accessible within 2 direction changes from a random location, while in the other systems the proportion varies between 17% and 32%.

Differentiation of scale based on linear extension of streets: The simplest way to describe the differentiation of scales is according to the linear extension of a street from a point – conceptually equivalent to the length of an axial line, as discussed by Hillier (2002), but made independent of specifying a discretization of the system. Technically, this is directional reach with the number of direction changes set to zero. The second and third data rows describe the average linear extension from a random position on the supergrids and a random position in the inserted local networks respectively. The ratio between the two values is provided in the next row. With Chicago, the ratio is small since most inserted streets traverse the whole area under study. In all other cases the ratio varies between 3 and 5, with most values between 4 and 5, as inserted streets are much shorter than those of the supergrid.

Differentiation of scale based on directional distances: Mean directional distances for the whole network, the supergrid streets and the inserted streets are provided in data rows 5-7. System means vary between 1.5 and 4.5, a range of simple val-



Figure 22 :

Distribution of directional distances. Lower values in red, higher values in blue.

ues that would be obscured if we used modes of relativization according to the number of discrete elements, such as those implicit in the measure of axial integration or angular integration. Row 8 provides the difference of the values in rows 6 and 7. As shown, with the exception of Chicago, where insert streets are not much different from supergrid streets, the directional distances associated with insert streets are greater than those of the supergrid by between 0.76 and 1.6 direction changes. Thus, the polarization of scales based on directional distances is much smaller than the polarization of street lengths. In this regard, the cases under consideration are similar to the theoretical grids discussed in the previous section. From an experiential point

of view, to be inside the local areas is to be only a small number of turns more removed from the rest of the system relative to being on the supergrid. Figure 22 presents a graphic representation of the variation of directional distances over the systems under consideration.

Directional distances from the supergrid: To further characterize the systems, we computed the mean number of direction changes from a random position on the inserted street network to the nearest supergrid street – row 9. And the proportion of total street length which is within 2 direction changes from the supergrid – row 10. It will be seen that the mean directional distance from the supergrid varies between 1 and 3, with most values lower or

Figure 23 :

Proportion of streets within 2 direction changes from supergrid (in red); supergrid shown in thicker red lines.



equal to 2. The proportion of the total street length which is within two direction changes from the supergrid varies between .62 and 1, with most values greater than 0.7. Figure 23 offers a visualization of the proportion of streets which is within 2 direction changes from the supergrid.

Supergrid as an independent system: The supergrid was analyzed as an independent system in all cases, after excluding all insert streets. The mean directional distances associated with the supergrid on its own are given in row 11. Essentially, values vary between 1 and 2, with Islamabad standing out as the example of a supergrid that engenders greater directional distances in order to respond to linear parks along natural valleys

and also in order to express the sector-center as a destination linked to the major streets but not traversed by them.

Each superblock as an independent system: Given the underlying idea of decomposition presented earlier, each superblock was analyzed as an independent system, including the supergrid spaces at its perimeter. Row 12 gives the mean directional distances associated with superblocks, in clockwise order starting from the northeastern quadrant. The mean for all superblocks is given in parentheses. The Perry-Whitten neighborhood is, of course, a single superblock. In all cases, superblocks are more integrated than the system as a whole. Los Angeles has the greatest differ-

		Beijing	Chicago	Gangnam Seoul	Islamabad G7	Los Angeles	Perry Whitten
1	Mean proportion of street length accessible within 2 direction changes	0.32	.90	0.22	0.15	.32	.17
2	Mean linear extension of super-grid streets (m)	1516.35	1622	1251.2	1230.2	1609	744.7
3	Mean linear extension of in-inserted streets (m)	370.21	1416.6	277.8	298	534.6	142.48
4	Ratio of linear extensions of supergrid streets and insert streets	4.1	1.15	4.5	4.13	3	5.23
5	Mean directional distance for whole network	3.53	1.64	3.66	4.22	3.84	4.47
6	Mean directional distance for supergrid streets	2.55	1.5	2.63	3.63	2.66	3.21
7	Mean directional distance for insert streets	3.72	1.68	3.82	4.39	4.17	4.76
8	Difference between the means of directional distance for insert streets and supergrid streets	1.17	0.18	1.19	0.76	1.51	1.55
9	Mean directional distance from insert streets to nearest super-grid street	1.74	1	2.05	1.59	2.03	2.67
10	Proportion of street length which is within 2 direction changes from supergrid	0.86	1	.73	.92	.80	.62
11	Mean directional distances for super grid as independent system	1.35	1.16	1.07	2.02	1.28	1.14
12	Mean directional distances for individual superblocks and mean of means for all super-blocks in each system.	2.47, 3.33, 2.75, 2.97 (2.88)	1.4, 1.53, 1.54, 1.4 (1.47)	3.06, 3.4 (3.23)	3.46, 2.97, 2.83 3.72 (3.24)	1.52, 3.89, 2.75, 4.08 (3.06)	(4.47)
13	Difference between mean directional distance for whole network and the mean of means of directional distance for individual superblocks	0.65	0.17	0.43	0.98	0.78	0
14	r ² for the relationship between the mean directional distance for each street segment relative to the whole network, and the shortest directional distance from the segment to the nearest supergrid street; significance values below.	0.91 <0.0001	0.07 <0.0001	0.73 <0.0001	0.81 <0.0001	0.98 <0.0001	0.82 <0.0001

Table 2:

Six areas analysed.

entiation of superblocks while, other systems are more homogeneous. Row 13 gives the difference between the mean directional distance for the entire networks and the mean of means of the directional distances for the superblocks. In Islamabad this is about one direction change reflecting the strong separation of superblocks; in Los Angeles it is about $\frac{3}{4}$ of a turn, reflecting the internal dendric structure of some superblocks. In other cases the difference is half a direction change or less, in other words the superblocks do not appear as more strongly integrated internally than they appear integrated into the network as a whole.

Taken together the above results serve to set some benchmarks against which other cases can be studied, and new designs can be developed. As important, they set parameters against which we can understand more tangibly the idea of decomposing directional distances in two components: directional distances along the supergrid and directional distances from the insert areas to the supergrid. In 2003, Kuipers, Tecuci and Stankiewicz (2003), suggested that from the point of view of spatial cognition we should distinguish between a reference skeleton and the relationship of any given location to the skeleton, rather than imagine that all possible paths and connectivity relationships are equally known or knowable. Accepting this idea, for a moment, we can see in the systems under consideration the directional distance from the skeleton would be modest at between 1 and 2 direction changes on average. However, the analysis allows us to go further. For all systems, we run linear regressions of the mean directional distance of each line segment and its distance from the nearest supergrid street. These correlations are shown in row 14. In all cases but Chicago, the minimum distance from the supergrid accounts for more than 70% of the variance in mean directional distance from the network as a whole. The low correlation for Chicago is clearly due to the fact that inserted

streets are as long as supergrid streets, thus creating greater uniformity of values.

Thinking about systems in this way does not only make sense from the point of view of spatial cognition. It is also more compatible with design intuition. A designer developing a superblock can work with two questions: first, how to maintain reasonably direct connections from the interior to the supergrid; second how to give the superblock an internal core, some coherence as an independent system. These questions are far more palpable than trying to intuit the integration of each street within a given superblock under consideration relative to all streets in the larger surrounding urban context, at any large radius of analysis. This is why it is important to systematically understand how patterns of global integration may arise from simpler local relationships.

9. An experimental condition: Supergrids with the historic centers of small French towns inserted

The question arises as to whether superblocks of the dimensions discussed in this paper can be conceptualized as systems equivalent to semi-independent neighborhoods, in the manner commonly desired by Perry and Doxiadis and implement in very different ways, through curvilinear street designs and through offset grids respectively. One way to think about this question heuristically is to set superblock design in comparison with the design of small towns that we associate with desirable urban integration patterns. In this manner, the specific ideas that Perry or Doxiadis brought to bear on neighborhood design are controlled for. Thus, in this section we examine a hypothetical condition.

Consider the historic centers of four small French towns, shown in Figure 24. Their quantitative profile is given in Table 3. Two of the towns are about the size of the average supergrid block considered in the previous section and two are larger, Avignon having an area equivalent to two blocks. The street

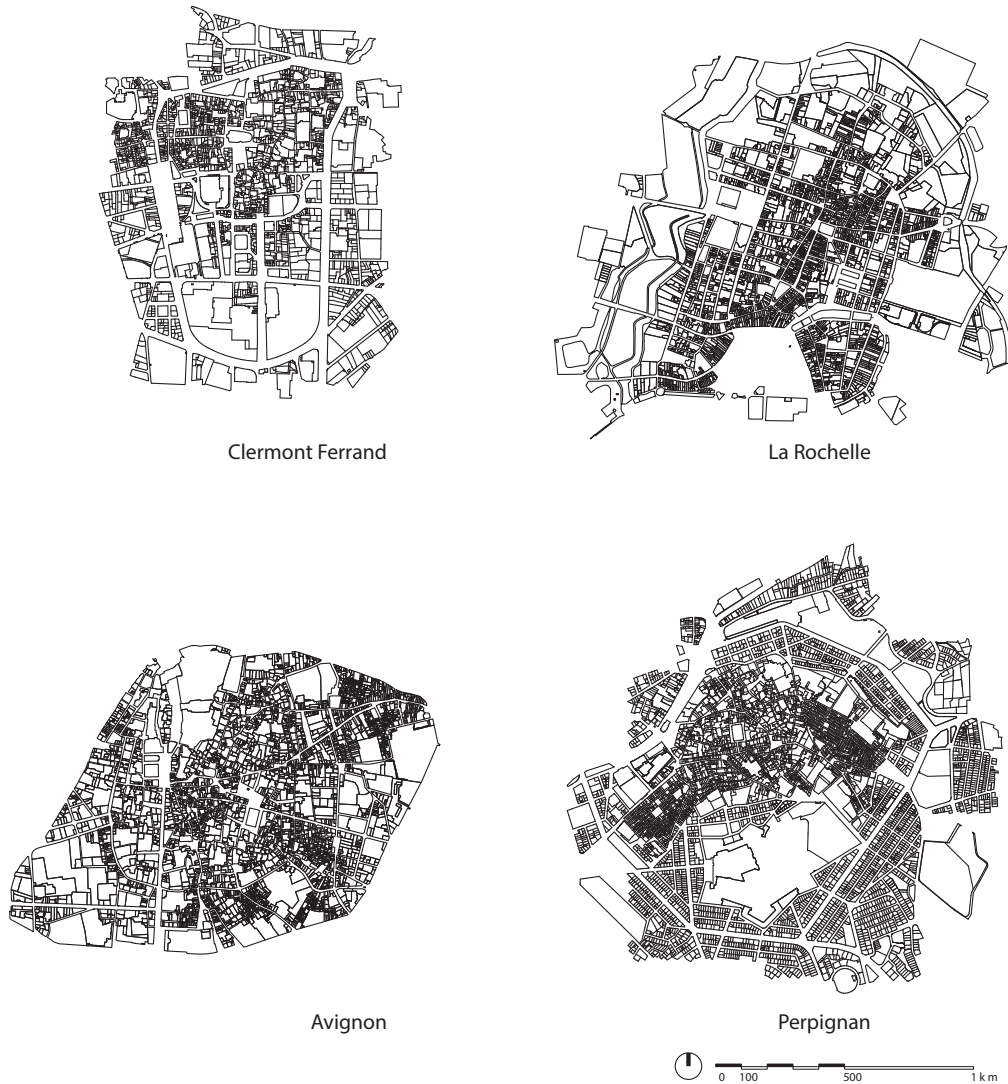


Figure 24 :

Plans of the historic centers of four small French towns.

systems of all four are as dense as those of Gangnam, Islamabad or the Perry Whitten neighborhood plan and thus denser than those of Chicago or Los Angeles. Block size resembles Gangnam and Islamabad and is considerably smaller than Chicago and Los Angeles. Distances between intersections are smaller than those of even Gangnam, ranging between 47 and 60 meters. Mean directional dis-

tances, with the same threshold of 15 degrees for counting a direction change, are generally greater than the supergrid areas examined earlier, by about one additional turn. Thus, from the point of view of standard measures of urban form the towns are comparable to at least some of the supergrid conditions examined earlier, but for the fact that they are 'deeper' in terms of directional distance.

Figure 25 :

Distribution of directional distance centrality in four French towns - red indicates lower distances, blue indicates higher distances.



In addition, the four towns have a structure of directional distance centrality which resembles a deformed wheel. This is shown in Figure 25 which graphically shows the distribution of directional distances. In other words, the urban layouts represent a syntactic type thought to connect effectively the parts of the town to each other and make the town as a whole well accessible to visitors and inhabitants

alike. However, they are all considerably larger than the town of Apt, the example used in the original illustration of the deformed wheel integration core (Hillier, Hanson, Peponis et al., 1983).

Figure 26.1 shows a supergrid, with major streets spaced at half a mile intervals (804 meters) with selected parts of the four towns inserted as internal structures of the superblocks. The selection was

	Avignon	Clermont Ferrand	La Rochelle	Perpignan
Area (ha)	155.37	72.13	65.06	110.02
Street length (km)	45.48	18.62	20.01	34.90
Street length/hectare (km)	0.29	0.26	0.31	0.32
Number of Road Segments	871	359	333	736
Mean distance between inter- sections (m)	52.22	51.88	60.09	47.42
Number of blocks	273	112	120	273
Mean block area (ha)	0.57	0.64	0.54	0.40
Mean directional distance	5.31	4.49	3.11	4.91

Table 3:

*Numeric profile of four
small towns.*

random but for a desire to find a chunk of urban fabric that can fill a superblock of 804 meters on the side. Where necessary, additional streets are included from the town maps, to fill the gap between the edge of the historic town and the edge of the superblock. We examine how the characteristics of this hypothetical condition compare to the real cases and the projects examined in the preceding section. Table 4 replicates table 2, adding a new column for the experimental condition. It will be seen that: The experimental condition: 1) differs from a regular grid more than the other cases (row 1); 2) is characterized by a greater differentiation of scale as measured by the linear extension of supergrid and insert streets (rows 2-4); 3) its mean directional distances are within the ranges associated with the other cases, but on their high end (rows 5-7); 4) the differentiation between the directional distances associated with supergrid and insert streets is greater (row 8); 5) the directional distances from inserted streets to the nearest supergrid street are within the range previously established, and so is the proportion of street length that is within two direction changes from the supergrid (rows 9 and 10); this is true despite the fact that the directional distances associated with individual superblocks are, on average, slightly higher than those of the

other systems (row 12); finally, the correlation between the mean directional distance of individual lines and their distance from the supergrid is very high and one of the highest in the sample under consideration (row 14).

Thus, from the point of view of the relationships discussed in this paper, the hypothetical example is only marginally different from the other cases examined. The marginal difference has to do with the increased sinuosity of the inserted street network, and the shorter linear extension of inserted streets compared to all cases other than the Perry-Whitten neighborhood design. Given that the fabrics chosen for experimental insertion came from smaller towns, it is hardly surprising that the experimental condition is more irregular, and characterized by shorter inserted streets than most of the other conditions studied.

Of course, as shown in Figures 26.2 and 26.3, there are considerable differences regarding the syntactic consequences of extracting traditional urban fabrics for filling-in superblocks. For example the upper right and the lower left quadrants (La Rochelle and Avignon inserts) are at polar opposite ends of the scale regarding the degree to which streets with high directional-distance-centrality penetrate the superblock and also the proportion

Table 4:

Hypothetical condition compared to the six areas previously analysed.

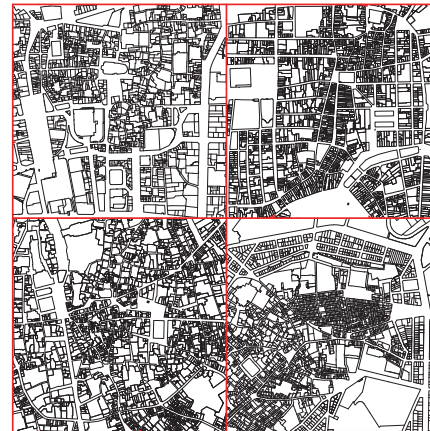
		Beijing	Chicago	Gangnam Seoul	Islamabad G7	Los Angeles	Perry Whitten	Hypothetical construct
1	Mean proportion of street length accessible within 2 direction changes	0.32	.90	0.22	0.15	.32	.17	.13
2	Mean linear extension of super-grid streets (m)	1516.35	1622	1251.2	1230.2	1609	744.7	1608
3	Mean linear extension of inserted streets (m)	370.21	1416.6	277.8	298	534.6	142.48	221.62
4	Ratio of linear extensions of supergrid streets and insert streets	4.1	1.15	4.5	4.13	3	5.23	7.26
5	Mean directional distance for whole network	3.53	1.64	3.66	4.22	3.84	4.47	4.5
6	Mean directional distance for supergrid streets	2.55	1.5	2.63	3.63	2.66	3.21	2.97
7	Mean directional distance for insert streets	3.72	1.68	3.82	4.39	4.17	4.76	4.7
8	Difference between the means of directional distance for insert streets and supergrid streets	1.17	0.18	1.19	0.76	1.51	1.55	1.73
9	Mean directional distance from insert streets to nearest supergrid street	1.74	1	2.05	1.59	2.03	2.67	2.20
10	Proportion of street length which is within 2 direction changes from supergrid	0.86	1	.73	.92	.80	.62	0.71
11	Mean directional distances for super grid as independent system	1.35	1.16	1.07	2.02	1.28	1.14	1.16
12	Mean directional distances for individual superblocks and mean of means for all superblocks in each system.	2.47, 3.33, 2.75, 2.97 (2.88)	1.4, 1.53, 1.54, 1.4 (1.47)	3.06, 3.4 (3.23)	3.46, 2.97, 2.83 3.72 (3.24)	1.52, 3.89, 2.75, 4.08 (3.06)	(4.47)	3.69, 2.67, 3.57, 4.39 (3.58)
13	Difference between mean directional distance for whole network and the mean of means of directional distance for individual superblocks	0.65	0.17	0.43	0.98	0.78	0	0.92
14	r ² for the relationship between the mean directional distance for each street segment relative to the whole network, and the shortest directional distance from the segment to the nearest supergrid street; significance values below.	0.91 <0.0001	0.07 <0.0001	0.73 <0.0001	0.81 <0.0001	0.98 <0.0001	0.82 <0.0001	0.96 <0.0001

of streets accessible within two direction changes from the supergrid. Deliberate design choices would have to be exercised in the manner of extracting portions of traditional fabric and the manner of inserting it in the supergrid if one of these two polar opposites was deemed desirable. Such exercise, however, would have limited value, for reasons that will be discussed in the last section of this paper.

10. Discussion

It is obvious that the ideas presented above can be developed with reference to more extensive studies than those already undertaken. For example, we still need to look at deformed supergrids. Also we still need to consider supergrids spaced at different intervals. More fundamentally, the generalization of the approach taken here into a more robust conceptual framework would require that we develop a methodology for identifying the equivalent of a “supergrid” when it is not as evident as in the examples chosen. This effort has already been initiated in earlier work by Peponis, Hadjinikolaou, Livieratos and Fatouros (1989) as well as Read (1999) and, of course, in the work by Hillier (2002) which has been more extensively cited above. Identifying the equivalent of an ‘emerging supergrid’ would in turn require that we complement current measures of closeness or betweenness centrality; specifically, street width and the density of intersections must be brought into the foundations of space syntax analysis. Note, in this regard, that the supergrid can as powerfully be associated with a local intensification of intersection density as it can be associated with by-passing ambient intersection densities. Such limitations notwithstanding, the work presented above can usefully be considered from two interacting points of view, in addition to those already articulated above: 1) the precision and clarity of measures; and 2) strategic design choices.

Consider the precision and clarity of measures first. Some of the most powerful measures



26.1



26.2



26.3

0 100 500 1 km

Figure 26 :

A hypothetical condition:

26.1: Superblocks filled with parts of the layouts of the historic centers of small French towns.

26.2: Distribution of directional distance centrality – lower distance values in red, higher distance values in blue.

26.3: Proportion of streets within 2 direction changes from the supergrid.

associated with space syntax bring together a number of different aspects of spatial organization. Take the question of size. Simple measures of the size of a street network might include the aggregate street length or the area covered. Using the number of syntactic 'elements' as an indicator of size merges magnitude and syntactic form because the number of elements is also a function of the sinuosity of the network (for axial lines and for street segment lines) or the density of intersections (for axial lines); more pedantically, it is also a function of decisions made at the time when the linear representation is constructed – there is no way to automate the generation of street center line maps as effective as the automation of axial maps. Furthermore, taking the number of elements as the basis for computing the mean of a system does not do justice to the distribution of street length on the ground and thus to the probability that a person will occupy any particular position. If the more integrated streets are longer, then averaging by the number of streets allows the shorter and less integrated streets to raise the value for the system. Finally, relativizing directional distance measures, as for example with 'integration' leads to values that are intuitively undecipherable and unitless. The statement that an element in a system "has integration value a for radius n " has less clear meaning than the statement that "when the radius is set to network distance m , the total street length that can be reached is L and the direction changes needed to get to a random position within the set of places reached are d ". The former statement seems clear to those familiar with space syntax terminology but remains imprecise: is a resulting from having more elements at varying distances, or is it resulting from having fewer elements nearer to the origin of the calculation? The later statement is clear to all because the situation is explicitly described and units are attached to the measures.

Unpacking syntactic ideas is of considerable value because it opens the way for enriching and rendering more precise some of the major space syntax theses, for example those associated with the attraction of movement towards integrated spaces, or those associated with the tendency of integrated spaces to anchor cognitive maps. It is of even greater value from the point of view of design. It helps focus design attention to magnitudes that can readily be manipulated and to consider design moves whose consequences are palpable. For example, the integration of an axial line might be increased by making the line longer in context (reducing sinuosity), by adding more intersections along its length, or even by increasing the density of streets in its vicinity. These are different design moves and it makes sense to unpack measures so that these moves can be independently as well as collectively considered and assessed.

We now turn to strategic design choices. Supergrids are a dominant form of metropolitan street networks in many parts of the world including, for instance, the USA, the Arab Peninsula, parts of South America and China. They are also associated with an idea that pervades much 20th century planning, namely the desire to create relatively well defined neighborhoods in the context of the larger city, as we acknowledge by including the Perry-Whitten as well as the Doxiadis proposals in our analysis – we did not include examples, such as the superblocks of Brasília which are driven by a programmatic opposition to traditional streets. When considering supergrids, a couple of stark strategic design choices become apparent. The first choice has to do with whether the supergrid acts like a boundary dividing urban areas, or an interface linking them together. This choice has a couple of dimensions to it. One dimension is the relationship between street network and land use. For example, Doxiadis places few primary uses on the supergrid of freeways that surrounds

a sector; communal destinations, or attractors, are hierarchically placed inside the sectors, with the primary attractors at their center. Perry and Whitten place some communal facilities (school, parks and church) in the middle of the neighborhood, but provide for retail at neighborhood edge, near the supergrid intersection, thus thinking of the edge as a common destination for several neighborhoods. Another dimension of the same strategic choice is the design of the supergrid section. In some cases supergrid streets can be crossed with great difficulty and at few limited crossings. Difficulty arises from the number of lanes, the absence or limited width of the median, the presence of physical obstructions. In other cases the supergrid can be crossed at most places where a local street is incident on it.

The second strategic design choice has to do with the tuning of the relationship between inserts and supergrid. This also has a couple of dimensions to it. First, inserted areas can be designed so that transitions from one to the next are only possible through the supergrid, or also possible directly, without travel along the supergrid. The supergrid can thus be the sole connector, or a preferable connector that bypasses local density to speed up longer trips. In some extreme cases, where the inserts are very sinuous, the supergrid can even be part of the shortest trips linking destinations inside the superblocks, when trip length is measured by direction changes. We have already indicated this through the construction of the theoretical examples (see Figure 20). The second dimension of the relationship between supergrid and inserted areas is whether the inserted areas have distinct centers of local convergence. This is where the 'deformed wheel' pattern of closeness centrality functions as a very useful shorthand. In the case of traditional towns, such as the four considered above, the pattern of closeness centrality is likely to include streets traversing the middle of the town;

the question is whether it also includes parts of the periphery. In the case of superblocks, the supergrid is most likely to have high values of closeness centrality based on directional distances; the question is whether centrality also includes parts of the inserted network and how extended these parts are.

Which brings us to considering Gangnam as a very interesting strategic design alternative regarding the space syntax of supergrids. Gangnam, now a new commercial and business center in Seoul, is a relatively recent development, urbanized from agricultural land in the 1970s. Land subdivision occurred under the Land Readjustment program which affected 40% of the urbanized areas of Seoul; Gangnam was the largest continuous area developed under the program. In Gangnam, high rise buildings and commercial frontages are placed on the supergrid. The supergrid functions as a system of convergence and confluence. At the same time, the inserted network of streets resembles a traditional deformed wheel pattern, supporting the creation of distinct local centers, with retail frontages, continuously growing from the supergrid inwards. Thus, an urban area structured along the principles present in Gangnam, would have two clearly layered and almost co-extensive scales of organization, local and global, each invested with uses that support urban liveliness. In abstract syntactic principle, Gangnam comes close to inserting the structure and scale of traditional smaller towns inside the superblocks of a modern Metropolis. This places it in interesting dialogue with all the other cases considered.

Ending with an evocation of 'abstract syntactic principle,' however, would be inappropriate. It would conceal a rather interesting design problem that we wish to make more explicit. In order for high density developments to be supported at the edge of the superblock, block sizes must be appropriately large. Larger block sizes at the edge may also be

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necessary to mediate the transition from the scale of the supergrid to the scale of the first parallel street in the interior. The centrality patterns at the center of the superblock might benefit by more intense block subdivision. This adjustment of block size to syntactic position is evident in Gangnam. However, as shown by the Perry-Whitten example, larger blocks in the interior of the superblock may be necessary to accommodate a range of uses, from local public open spaces, to schools. Thus, one aspect of the design problem is the calibration of an abstract syntactic idea to requisite block dimensions. Another aspect of the design problem is the calibration of visual relationships. Without such calibration the interior of the superblock will be dwarfed by the higher density development of the perimeter. Turning contrasts of visual scale to an advantage rather than a disadvantage is an interesting syntactic problem in its own right. Finally, the interweaving and calibration of high volume vehicular access networks, lower volume through-traffic networks and pedestrian networks is a major issue, one that Doxiadis grappled with when he superimposed a covering pedestrian grid (with offsets intended to define local quarters) upon dendritic networks for vehicular access and a sparse network of vehicular through movement. In short, we propose that work such as presented in this paper is most useful when it leads to the definition of a design problem, thus inviting a next phase of exploration of syntactic principles through design propositions rather than through the analysis of existing cases and experiments only.

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References

- Doxiadis, C.A. (1968), *Ekistics: an introduction to the science of human settlements*, New York: Oxford University Press.
- Hillier, B. (2002), 'A theory of the city as object: or, how spatial laws mediate the social construction of urban space'. In: *Urban Design International*, Vol. 7, p. 153-179.
- Hillier, B., Hanson, J., Peponis, J., Hudson, J. and Burdett R. (1983), 'Space syntax, a different urban perspective'. In: *Architects' Journal*, Vol. 178, p.47-63.
- Kuipers, B., Tecuci, D.G. and Stankiewicz, B.J. (2003), 'The Skeleton In The Cognitive Map: A Computational and Empirical Exploration'. In: *Environment and Behavior*, Vol.35, p.81-106.
- Peponis, J., Bafna, S. and Zhang, Z.Y. (2008), 'The connectivity of streets: reach and directional distance'. In: *Environment and Planning B: Planning and Design*, Vol. 35, p.881-901.
- Peponis, J., Hadjinikolaou, E., Livieratos, C. and Fatouros, D.A. (1989), 'The spatial core of urban culture'. In: *Ekistics-the Problems and Science of Human Settlements*, Vol. 56, p.43-55.
- Perry, C.A., Heydecker, W.D., Goodrich, E.P., Adams, T., Bassett, E.M. and Whitten, R. (1929), *Neighborhood and community planning*. New York: Regional Plan of New York and its Environs.
- Read, S. (1999), 'Space syntax and the Dutch city'. In: *Environment and Planning B: Planning and Design*, Vol. 26, p.251-264.
- Shpuza, E. (2014), 'Allometry in the syntax of street networks: evolution of Adriatic and Ionian coastal cities 1800-2010'. In: *Environment and Planning B: Planning and Design*, Vol. 41, p.450-471.